Implementation Of Optical Logic Unit Based On Nonlinear Properties Of Semiconductor Optical Amplifiers

A Thesis

Submitted in fulfillment of the requirement for the award of degree

of

Master Of Engineering

In

Electronics And Communication

Submitted by

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CERTIFICATE

I, Kanika Aggarwal hereby declare that the thesis report entitled, **"Implementation Of Optical Logic Unit Based On Non Linear Properties Of Semiconductor Optical Amplifier"** is an authentic record of my study carried out as requirement for the award of degree of M.E (Master of Engineering) in Electronics and Communication Engineering Department, Thapar University, Patiala under the guidance of Dr. Hardeep Singh during January to June 2016.

The matter presented in this report has not been submitted in any other university or institute for the award of any degree.

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DECLARATION

I hereby declare that the work which is being presented in the seminar entitled, **"Implementation Of Optical Logic Unit Based On Non Linear Properties Of Semiconductor Optical Amplifier "**, in partial fulfillment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering submitted in Electronics & Communication Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Dr. Hardeep Singh** and refers other researcher's works which are duly listed in the reference section.

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ABSTRACT

Optical communication systems operating at gigabits per second are commercially available and the data rates are achieved above 10 Tb/s in research laboratories. In order to achieve such data rates, all-optical computing should be realized using digital optical devices. These days, ultra-fast and all-optical processes are required in the high-capacity photonic networks to avoid optoelectronics conversions.

The key components for these all-optical networks amongst others are all-optical regenerators, wavelength converters, packet switches and all optical memory. All optical gates, optical arithmetic and logic circuits and flip-flops form important subsystems of these components. An all-optical arithmetic and logic unit is the integral part of optical computing and data processing. So, there is a need of all optical digital devices which provide better performance (in terms of simple structure, operation at multi Gbs-1 speeds, photonic integration etc.) for future all optical networks. With the advances in the optical semiconductor device design and fabrication techniques, the semiconductor optical amplifiers (SOAs) have become a preferred choice for use in future optical communication networks for in line amplification and optical switching. This thesis mainly designs, characterizes and investigates all optical arithmetic and logical devices using on nonlinear properties of semiconductor optical amplifiers. The all optical digital devices are implemented considering various important design aspects such as data rate; simple structure potential for integration etc.

Semiconductor optical amplifiers (SOAs) are very attractive nonlinear elements for the realization of different logic functions, since they can exhibit a strong change of the refractive index together with high gain. In this report, a principle of operation, simulation step and experimental result of different all-optical logic gates (AND Gate, OR Gate, XOR Gate) are well presented. These gates are based on the nonlinearities on SOAs. The experimental results were exactly matched with standard results and increasing the speed of optical logic gates. All-optical logic gates became key elements in the realization of node functionalities, as add drop multiplexing, packet synchronization, clock recovery, address recognition, and signal processing.

Semiconductor optical amplifiers (SOAs) are very attractive nonlinear elements for the realization of different logic functions, since they can exhibit a strong change of the refractive index together with high gain. Moreover, different form of fiber devices SOAs allow photonic integration. The nonlinear behaviour that is a drawback for the SOAs as a linear amplifier makes it a good choice for an optically controlled optical gate**.**

In this an optical gate architecture is proposed to perform AND, OR and NOT logic gates using a single SOA. All optical logic operations are simple and reconfigurable and are implemented using RZ modulated signals at 40 Gb/s operational speed. Contrast ratio and extinction ratio values have also been analyzed for the above mentioned logic gates.

Maximum extinction ratio and contrast ratio achieved are 19dB and 17.2 dB respectively.Simple structure and potential for integration makes the proposed architecture an interesting approach in photonic computing and optical signal processing.
Therefore, this study establishes the designs and investigations of all optical arithmetic and logical devices, which are very essential in the high capacity core networks in order to avoid optoelectronics conversions and deal with the revolutionary growth of internet traffic for the future photonics networks.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

UNI	Ultrafast Nonlinear Interferometer
OBF	Optical Band Pass Filter
XPM	Cross Phase Modulation
OTDM	Optical Time Division Multiplexing
SOA	Semiconductor Optical Amplifier
DWDM	Dense Wavelength Division Multiplexing
WDM	Wavelength Division Multiplexing
O-E-O	Optical-Electrical-Optical
OAMP	Optical Amplifiers
TOAD	Terahertz Optical Asymmetric Demultiplexer
Q	Quality
POlSK	Polarization Shift Keying
BER	Bit Error Rate
SPM	Self Phase Modulation
ER	Extinction Ratio
XGM	Cross Gain Modulation
CR	Contrast Ratio

FWM	Four Wave Mixing
ASE	Amplified Spontaneous Emission
OFA	Optical Fiber Amplifier
NRZ	Non Return To Zero
RZ	Return To Zero
SLALOM	Semiconductor Laser Amplifier In A Loop Mirror
NOLM	Nonlinear Optical Loop Mirror

CHAPTER 1

Introduction

1.1 OPTICAL NETWORKS

Communication means exchange of information from one place to another through a medium.There are many mediums which can be used for data transmission like twisted pair cable, coaxial cable system.But optical fiber is given high importance due to its huge capacity.Within last few days optical packet networks has drawn a good attention .As now a days optical packets are used to carry the information.

Optical fiber can transimt data at rate beyond 1 gb/sec.The switching function is also one of the major application of optical networks which can be used for communication purpose.It is used in all information processing and information transmission system..Maximum communication apparatus is set up on electrical pulses,which means that light pulses have to be transformed into electrical signal intensities,,,transmit and then again transformed to electrical signal.This is called as optical to electronic to optical conversion.This scenario of OEO conversion would not be able to handle routing of large number of data and not even at a reasonable cost.The biggest advantage of optical switching inspite of electronic switching is that,there would be no need of OEO conversions.

While comparing the capacity of optical switches it is realised that bandwidth handling capability of optical switches in much more high than that of electronic switches.An optical fiber communication consist of three components transmitter, transmission path and reciever.An optical signal is generated with the help of optical source.Data source and optical signal is fed to modulation and the resulting signal is passed through optical fiber which is available transmission path.The signal is detected at receiver side with the help of optical detector.The detected signal can be converted into desired signal with the help of demodulator.Today we want to realize all optical computers with the help of digital optical elements ie optical logic gates.Optical logic gates are essential elements for realizing node functionalities ,as add drop multiplexing ,packet synchronization,clock recovery,address recogonition and signal processing.These optical logic gates can be designed with the help of semiconductor optical amplifier(SOA).

1.2 OPTICAL AMPLIFIERS

Optical fiber communication networks have grown rapidly with respect to the deployment and capacity of the networks over the past few decades. There is a growing demand for the networks having large capacity and capability for transparent routing. Continuous up gradation and advances are required to be made in the signal amplification and other processing techniques. Optical amplifiers have made possible a number of significant advances

in the optical networks. Light gets attenuated during propagation over long distances in optical Optical amplifiers are mainly utilized to amplify optical signals. Optical switching and wavelength conversion are also some of the important applications of these devices.
There are two types of optical amplifiers ie OPTICAL FIBRE AMPLIFIER and SEMICONDUCTOR AMPLIFIER.For in line amplification optical fiber amplifiers are used.Semiconductor amplifiers works as optical switch ,modulator and wavelength converter in transparent optical networks. Their comparison is given in Table 1.1. SOA is very small in size and pumped electrically. The SOAs differ from other doped fiber amplifiers in the way of achieving population inversion. The population in the SOA are carriers (i.e. electrons or holes) in a semiconductor material rather than ions in various energy states.
This device is less expensive than the Erbium Doped Fiber Amplifier (EDFA) and can be integrated with modulators, semiconductor lasers, etc. SOAs are sensitive to polarization. The important factors responsible for this is its waveguide structure and gain material. So in order to improve its polarization sensitivity waveguides with square-cross section and strained quantum-well material are used.

Feature	**SOA**	**OFA**
Maximum Gain	30-50 (db)	32 (db)
Insertion Loss	0.1-2 (db)	5(db)
Polarisation Sensitivity	No	Less than 2 db
Pump	Optical Source	Electrical Source
3 db Bandwidth	30 (nm)	30-50(nm)
Non Linearities	Negligible	Present
Power Output (Saturation)	10-15(db)	15-18(db)

Table 1.1 Comparison between SOA and OFA

Now a days fiber amplifier is being prefered for the conventional applications of optical fiber communication systems . One of its example is in-line amplification of the optical signals for the compensation of optical fiber losses. The reason behind this was mainly due to the fact that the fiber amplifiers like EDFA, provide higher internal gain. They are not disturbed by the internal noise which otherwise can cause the gain to vary dynamically as its in SOA implementations.
SOA is very promising for its use in evolving optical fiber communication networks. This is due to the advances in the device designing and optical semiconductor fabrication techniques. SOA can be used for amplifying optical signals and also have many functional applications. These include wavelength conversion, an optical switching, regeneration, in line amplification

and mid span spectral inversion. These are the main functions required in transparent optical networks. Transparent optical networks do not require any conversion of optical signals into the electrical domain and vice-versa. Polarization independence compact size, low power consumption and high speed are the salient features of the device.

1.3 Principle of Semiconductor Optical Amplifier

Figure 1.1 shows the schematic configuration of device. An electrical current drives the device. Input signal is imparted gain via stimulated emission by the active region in the device. Noise accompanies the output signal. The added noise is produced due to amplified spontaneous emission (ASE) during the amplification process.

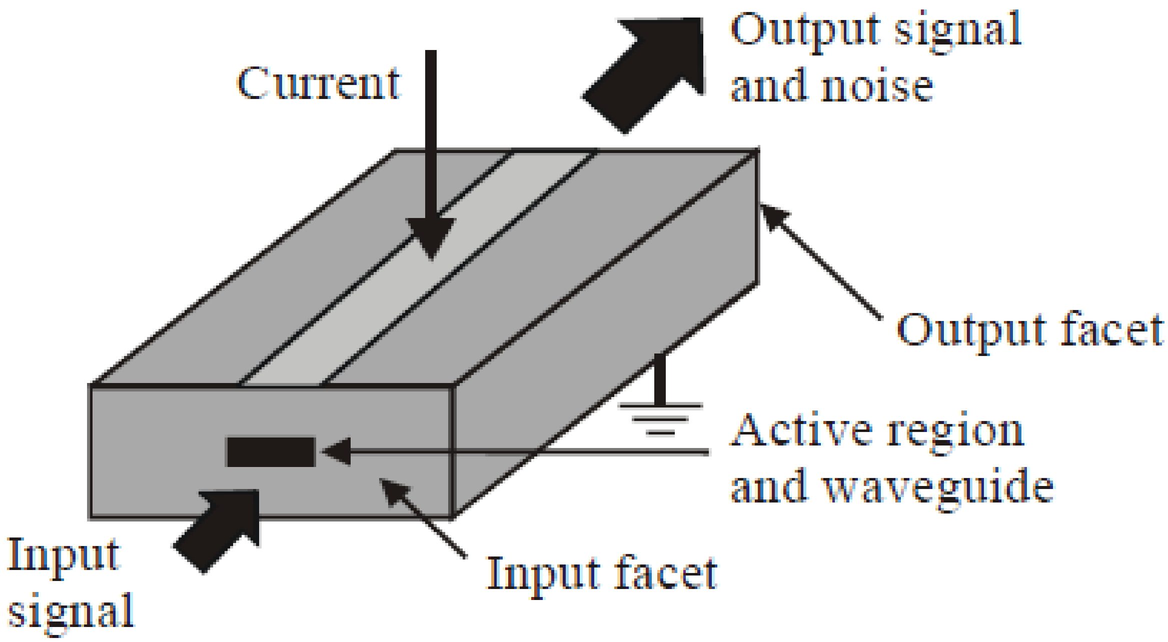
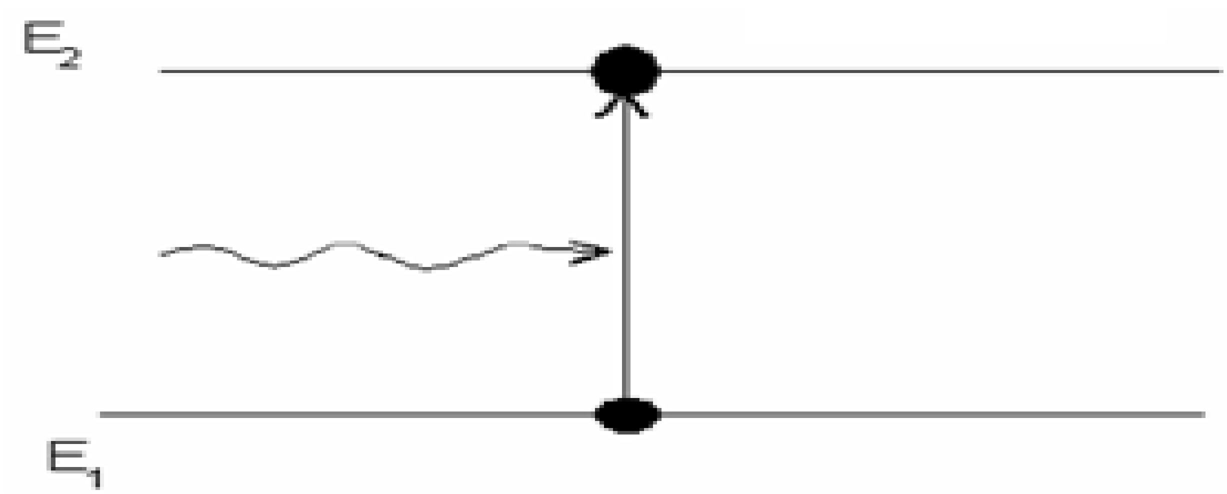


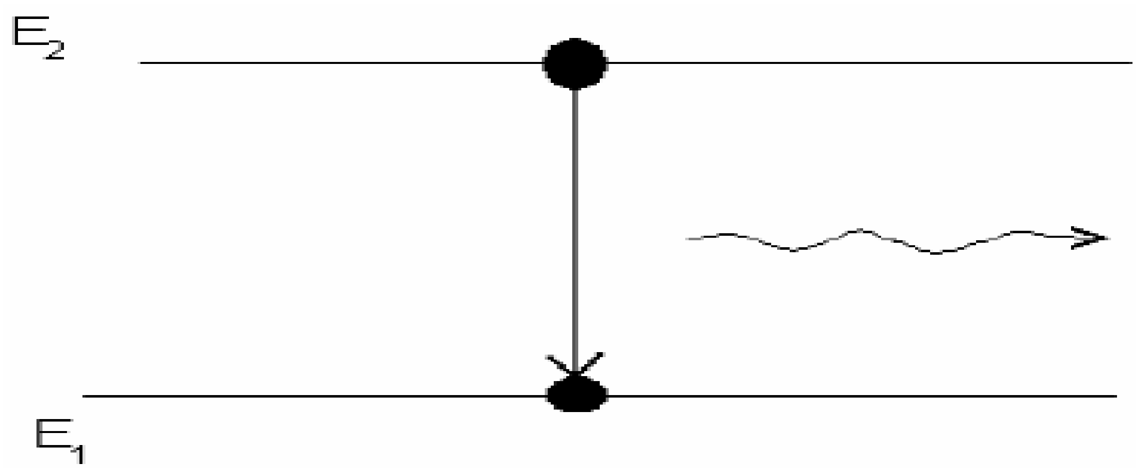
FIG 1.1 Schematic configuration of an SOA

The input signal power along with internal noise generated during the amplification process influence the gain of a semiconductor optical amplifier. Gain decreases with the increase in the power of input signal. Carrier recombination lifetime (few hundred picoseconds) determines the gain dynamics of the device . The amplifier gain responds quickly to the variations in the power of the input signal. Signal distortion may be caused by dynamic change in the gain of the amplifier. Signal distortion may become more severe if the bandwidth of modulated signal is further increased . The SOA utilizes stimulated emission principle for amplifying an optical information signal. The optical input signal is applied to the active region of the device with the help of coupling . The injection current delivers the external energy to pump the electrons to the conduction band. The input optical signal stimulates the transition of electrons in the downward direction to valence band. This results in emitting of photons with the same amount of energy and wavelength as of the input signal. An amplification of optical signal is achieved in this manner.

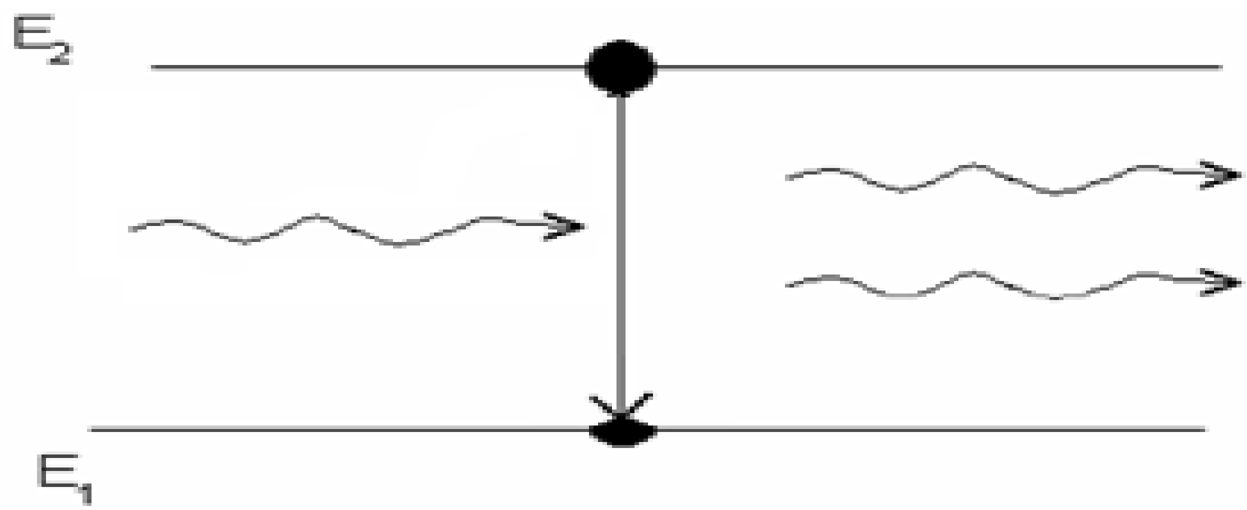
Atom exists only in certain discrete energy state. Absorption and emission of light cause them to make a transition from one discrete energy state to another state. The energy of the emitted light is related to difference between the two energy states. One of them is the higher energy level (E2) and the other is lower energy level (E1) as shown in Figure 1.2(a). When photon with associated energy E strikes an atom which is at lower energy level (E1), it may cause the atom to get excited to higher energy level (E2). This phenomenon is known as absorption as shown in Figure 1.2(a). As atom in energy state E2 does not remain stable, the atom yield to lower energy state in arbitrary manner by generating output photon as shown in Figure 1.2(b). This mechanism is called spontaneous emission. Similar to the approach used in a laser, principle of stimulated emission is used in optical amplification . When the incident photon with energy $E = hc/\lambda$ interacts with electron in the upper energy level, the stimulated emission takes place, causing the photon to return back into lower energy state with generation of second photon as shown in Figure 1.2(c), In this relation, h, c and λ are Plank's constant, velocity of light in vacuum and wavelength of light respectively . The amplification of light takes place, when input as well as generated photons are in same phase and discharge two or more number of photons.
For achieving better optical amplification, the density at upper energy state should be larger than population at lower energy state i.e. $N_1 < N_2$, where N_1 and N_2 are population densities of lower energy level and upper energy level, respectively. This is phenomenon is known as population inversion. Population inversion could be achieved by using external source (called pump) which is responsible to excite the electron into higher energy level.



(a) Absorption Process



(b) Spontaneous emission process



(c) Stimulated emission process

Figure 1.2: Different processes of optical amplification; (a) Absorption process, (b) Spontaneous emission process and (c) Stimulated emission process

The stimulating emission process can be dominating only in the case if requirement of population inversion condition is fulfilled. For the case of SOA the requirement is satisfied by doping the n-type and p-type cladding layers to such a high level that the Fermi level separates the band gap in forward bias condition of p-n junction. The rates of three types of emission processes such as absorption, spontaneous emission and stimulated emission are given as

$R_{spon} = AN_2$

$R_{stim} = BN_2\rho_{em}$

$$R_{abs} = B'N_1\rho_{em} \quad (1.1)$$

Where B and B' are constants. ρ_{em} is the spectral density of the electromagnetic energy. Also, N_2 is the atomic density of excited state. In the condition of thermal equilibrium, the atomic densities at the two levels are distributed as per Boltzmann statistics ,

$$\frac{N_2}{N_1} = \exp\left(\frac{-\mathrm{E}}{\mathrm{K_B T}}\right) \equiv \exp\left(\frac{-\mathrm{hf}}{\mathrm{K_B T}}\right) \tag{1.2}$$

Where K_B and T are the Boltzmann's constant and the absolute temperature respectively. As N_1 and N_2 will not change with respect to time in the condition of thermal equilibrium, the upward transition rate and the downward transition rate has to be kept same.

$$AN_2 + BN_2\rho_{em} = B'N_1\rho_{em} \tag{1.3}$$

$$\rho_{em} = \frac{A/_B}{(B'/_B)exp\left(\frac{hf}{K_b T}\right)-1} \tag{1.4}$$

The stimulated emission and absorption rates are achieved similarly and are given as follows

$$R_{stim}(\omega) = \int_{E_c}^{\infty} B(E_1, E_2) f_c(E_2)[1 - f_v(E_1)]\rho_{cv}\,\rho_{em}\partial E_2 \tag{1.5}$$

$$R_{abs}(\omega) = \int_{E_c}^{\infty} B(E_1, E_2) f_v(E_2)[1 - f_c(E_1)]\rho_{cv}\,\rho_{em}\partial E_2 \tag{1.6}$$

Where f_C E_2 are the occupation probability electrons of conduction band and f_v E_1 are the occupation probability electrons in valence band respectively. Also, ρ_{em} ω is the spectral density of photons, is joint density of the states and E is the energy of conduction band. When injection of carriers in active layer becomes larger than a certain value, which is known as transparency value, population inversion takes place and optical gain is exhibited by active region. The input optical signal propagating inside the active layer will then be amplified as ex, where g is defined as gain coefficient. In this g is proportional to $R_{stim} -$. Where g is the function of injected carrier density N, then peak value of gain g_p depends upon N which is given by empirical approach as

$$g_p N = a\,N - N_t \quad \left({}^{I_t}/_q - N_t\right) \tag{1.7}$$

In this equation N_t represents the transparency value of the carrier density and the differential gain is represented by symbol . Typical value of a for InGaAsP amplifiers is in the range 2 – 3 × 10^{-16} cm^2. Typical value of N_t for InGaAsP amplifiers is in the range 1.0 –1.5 × 10^{18} cm^{-3} . The small signal gain can be described by the following expression.

$$g_0 = (\,\Gamma\alpha\,/V) \tag{1.8}$$

In this equation Γ and α are defined as the confinement factor and the differential gain respectively. V is the active volume of the device. I, q and N_t are the bias current, charge of electron and transparency carrier density respectively. Also τ is carrier lifetime which represents the total recombination time of charge carriers in absence of any stimulated recombination.
Carrier lifetime is defined as $R_{spon} + R_{nr} =$ R,where N is carrier density and $R_{n\ r}$ is non radiative recombination rate. R_{spon} and R_{nr} increase nonlinearly with increase in N as given by the following equation

$$R_{spon} + R_{nr} = AN + BN^2 + CN^3$$

Where A represents nonradiative coefficient, which is due to recombination at defects or traps. B and C represent the spontaneous radiative recombination coefficient and Auger coefficient respectively. The carrier lifetime thus becomes dependent on N and it can be obtained by using expression $1/\tau = (A + BN + CN^2)$.

1.4 Optical Logic Unit

An all-optical arithmetic and logic unit is the integral part of optical computing and data processing. By means of an arithmetic and logic unit, so many binary logic operations such as AND, OR, NOT, NOR, flip-flop (used as memory unit for storage), data comparator, shifting, counting etc., as well as some arithmetic operations, such as addition, subtraction, etc., can be performed. An optical arithmetic and logic unit may be developed by exploiting nonlinear properties of an SOA. Basic building blocks required to implement such an optical logic processor are the optical logic Gates and SOA is found to be the very promising in this aspect.

1.4.1 Architectures for all-Optical Logic Gates

The use of optical fibre as well as semiconductor elements has facilitated the development of all optical architectures for logic gates. Next, the most important all optical configurations for implementing logic gates will be presented, describing their main advantages and disadvantages as well as their applications.

1.4.2 Sagnac Interferometers

The Sagnac interferometer consists of an optical ring cavity in which two light beams are propagating in opposite directions. These two beams interfere at a beam splitter and as the length of the optical path of the ring cavity is the same; both the clockwise and counter clockwise beams interfere with the same phase. If, however, the interferometer is rotating, then the light that goes round in the direction of rotation will have a shorter distance (as the mirrors of the cavity are moving towards it) than the other light beam (which experiences the mirrors as receding), and the phase will be different. Most common interferometric approach for optical signal processing is NOLM. Modifications of this have also been proposed to implement, for example, demultiplexers, switches and optical gates. This is the case of the TOAD, the SLALOM and the SOA assisted SAGNAC interferometers.

A. NOLM

One of the first architectures used to implement logic functions in the optical domain was the nonlinear optical loop mirror. This configuration presents some drawbacks and limitations. For example, this configuration works properly only if there is no interaction between the signals counter-propagating inside the loop. This supposition is valid only if the pulse length is shorter enough in comparison with the fiber length. If this condition is not achieved, the influence between the two signals cannot be neglected, since there are crossed-interaction effects. One more limitation is derived from the fibre length to use in order to achieve a notable phase shift. The first NOLM that was used required a 2 km length fibre to achieve a complete demultiplexing and switching function. Later on, this length has been reduced to 10 m, but even so it still being very difficult to integrate. Moreover, the energy of the control pulse needed to achieve the nonlinear effect in the fibre is too large, in the order of tens of picojoules, which limits the performance in real systems.
On the other hand, the main advantage of this configuration is that, due to the fact that switching is based on a passive element, high bit rates operation is achievable. In addition, it does not require interferometric alignment, is robust, and is of simple construction. Using this configuration several functions may be implemented. It has been used to realize reconfigurable all-optical logic gates for ultra-fast applications .

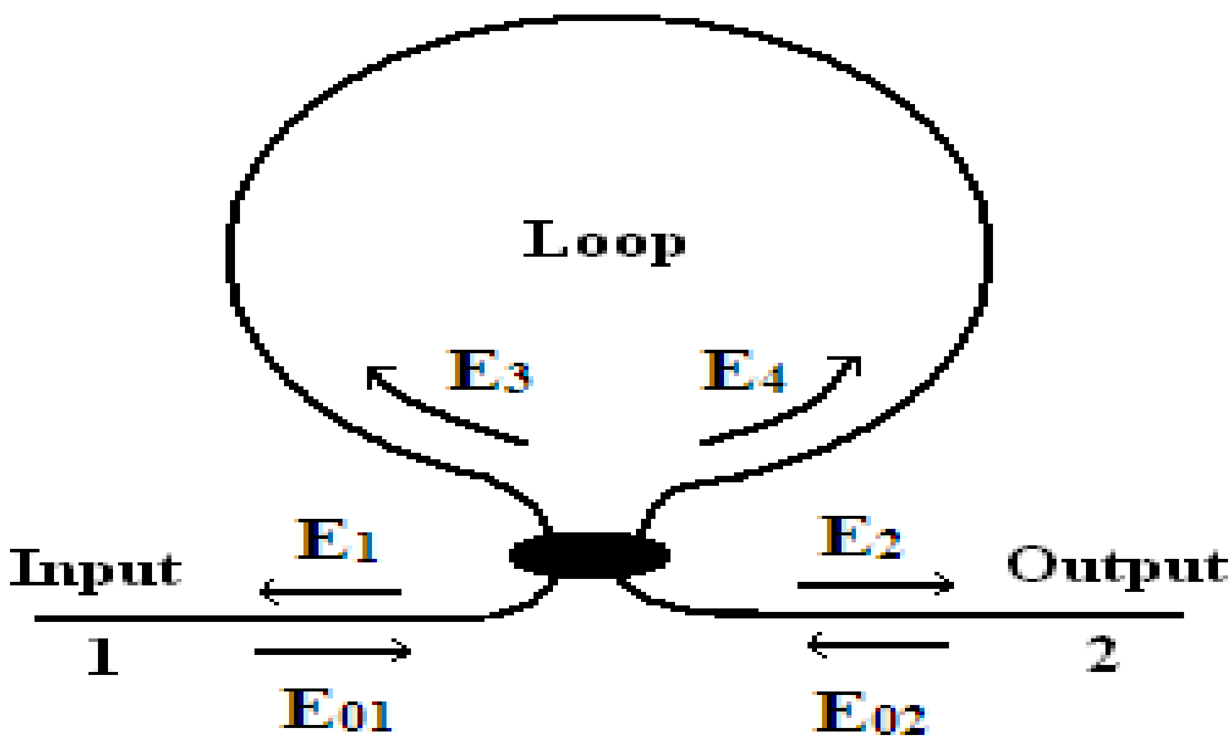


Figure 1.3: The original optical NOLM based on a fibre loop.

B. TOAD

The terahertz optical asymmetric demultiplexer consists of a nonlinear optical element asymmetrically placed within a short fibre loop and an intra-loop 2x2 coupler used to inject a control pulse. A signal pulse enters the loop through the main coupler and produces two pulses in the loop. As the pulses traverse the loop, the clockwise pulse and the counterclockwise pulse are always located on opposite sides of the loop, equidistant from the midpoint. Each pulse passes through the nonlinear element once, and they return to the main coupler at the same time. Under these conditions, the pulses arrive at the output coupler synchronised and in-phase. Both pulses interfere as in an ordinary loop mirror and do not emerge from the output port. If a control pulse is injected into the loop via the intra-loop 2x2 coupler just after one of the pulses passed through the nonlinear element and before the second one did it, the behaviour of the device changes. The control pulse passes once through the nonlinear element, modifies its optical properties and then passes out of the loop. When the second pulse reaches the nonlinear element, the conditions of the nonlinear element are not the same that those of the first pulse. As a result the destructive interference between the two pulses at the TOAD's output is incomplete, and a pulse is present at the output.

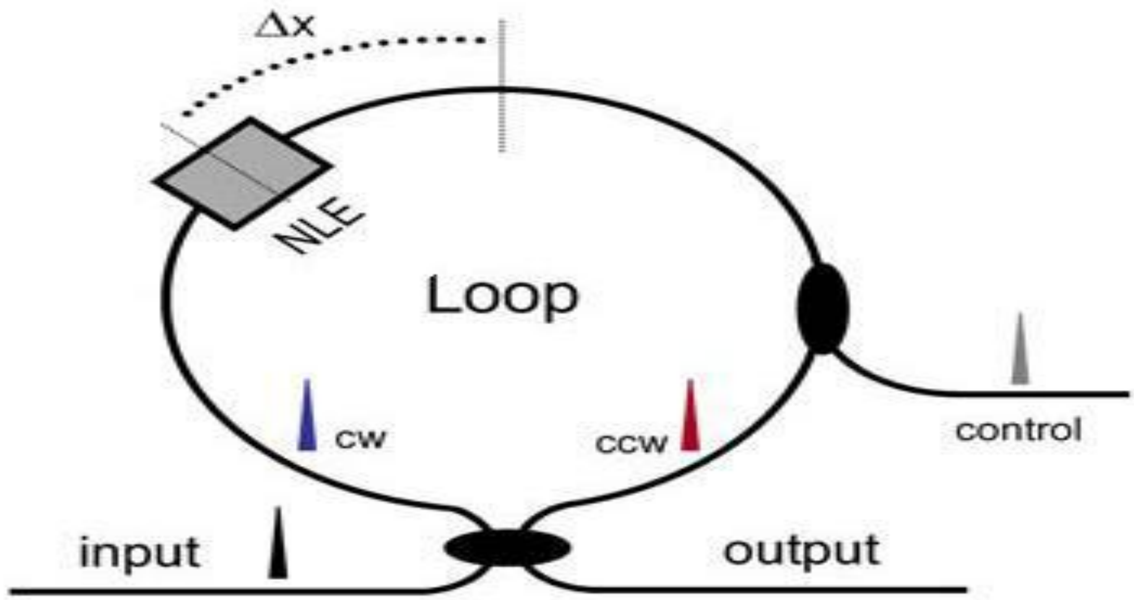


Figure 1.4: The terahertz optical asymmetrical demultiplexer.

Usually the nonlinear element used in the TOAD is an SOA. One limitation of the TOAD approach is the finite propagation time of the pulse across the SOA. If the offset of the SOA from the centre is decreased, the effective SOA length that the two counter propagating pulses see is reduced. The decrease in effective SOA length leads to a reduction in the contrast ratio of the TOAD switching and thus, an excess power penalty. The effective length of the SOA required for producing the relative π phase shift places a practical limitation on the switching window size of the TOAD to be greater than the propagation time of the pulse through the SOA. In cascaded configurations using TOADs certain stability to thermal effects is observed. This is because the counter-propagating pulses in each TOAD travel through the same span of fibre. The integration of the TOAD is currently a difficult problem yet to be solved.

C. SLALOM

This device is based on the Sagnac interferometer. However, its operation does not depend on the optical nonlinearity of the fibre but on the optical nonlinearity of a semiconductor laser amplifier (SLA) in the fibre loop.

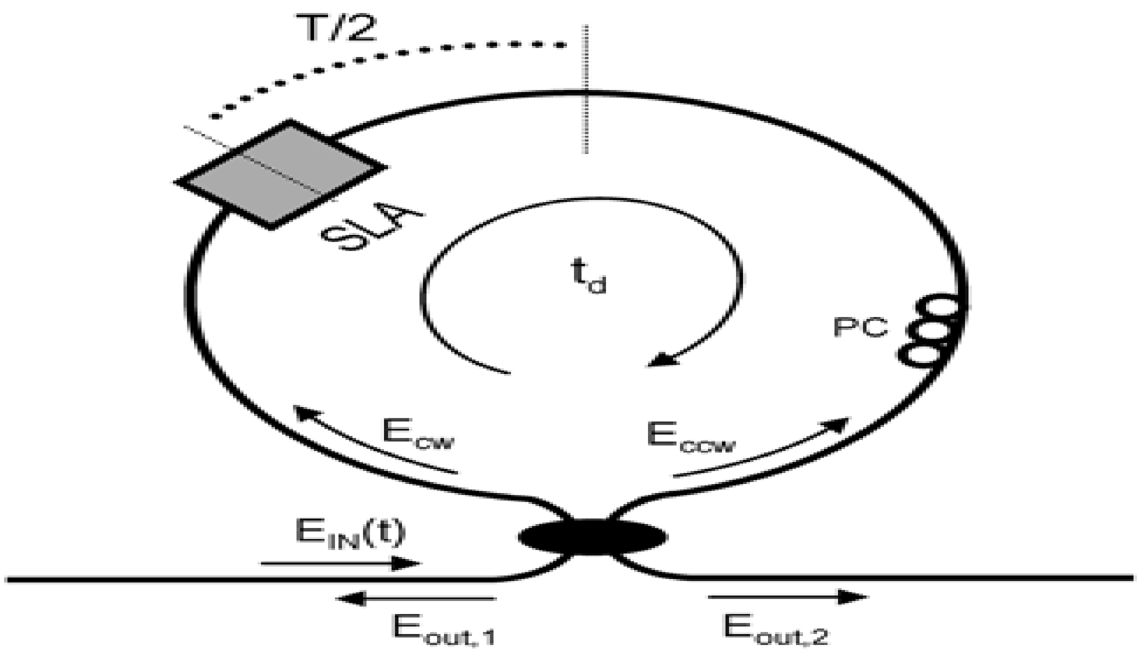


Figure 1.5: The SLALOM basic configuration.

As compared to the NOLM, the SLALOM has two advantages. Firstly, the device may be very compact so that integration on a chip is possible. Secondly, the required optical power is of the order of 1 mW. A disadvantage is that the operation speed is generally lower. It is of the order of a few GHz for most applications of the SLALOM except the applications as demultiplexer. The SLALOM is a configuration that may be used as an all-optical header processor based on correlation pulses, an all optical NOT gate , an all-optical binary half-adder, a phase comparator in a clock recovery scheme and a number of applications on photonic systems, like pulse shaping, decoding, retiming and time-division demultiplexing.

1.5 DIRECTIONAL COUPLERS

Directional couplers are passive structures that are often utilized in the area of communication and networking. A salient characteristic of directional couplers is that they are unidirectional. Power entering in the output port is transferred to the isolated port.

The basic construction of couplers includes two transmission lines placed nearby each other so that power entering in one transmission line is transferred to another. The devices operating at microwave frequencies commonly use this technique. Also, waveguide designs can be used at microwave frequencies, particularly the higher bands.

feedback, combination of feeds to and from the antennas, provision of taps like cable TV, antenna beam formation and separation of transferred and received signals on cellular phone lines.

The symbols used for the couplers are as displayed in figure 1.1. The sign noticeable on it denotes the coupling factor of the directional coupler. These couplers consist of four ports. Port 1 is called the input port from where the power enters. Port 3 is called the coupled port where some part of the power inputted to port 1 is coupled. Port 2 is called the transmitted port where the signal from port 1 is outputted, minus the part that goes to port 3. The couplers are often not asymmetrical so there is a port 4, called the isolated port. A part of the power entering port 2 will be transferred to port 4. But, the coupler is not frequently utilized in this way and port 4 is often ended with a matched load. This can be done within the circuit and port 4 is not available for use. This leads to a 3-port device, therefore the importance of the additional notation for directional couplers.

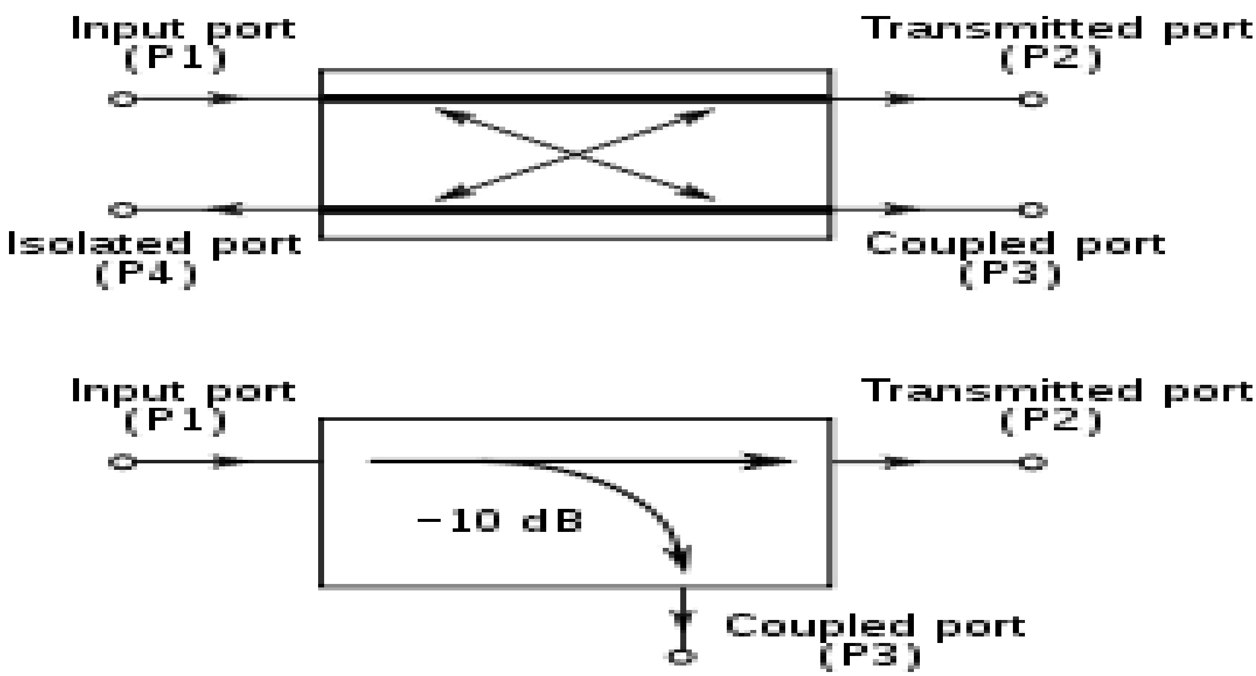


Figure 1.6 Two symbols used for directional couplers

CHAPTER 2

2.1 Logic Gates based on Nonlinearities in Semiconductor Optical Amplifiers

Nonlinear effects make SOA a very interesting device for applications in optical networks. Semiconductor optical amplifier (SOA) exhibits various non linear effects, which restrict it to use for various applications in optical communication systems . These same nonlinearities can be used for ultra fast switching and gating applications. SOA nonlinearities are mainly caused by carrier density variations in the amplifier. Amplifier input signals are responsible for the carrier density changes . There are four main types of nonlinearities: cross phase modulation (XPM), Cross gain modulation (XGM), self phase modulation (SPM) and four wave mixing (FWM).

2.2 Cross-Gain Modulation

The XGM effect results in the change of the semiconductor optical amplifier gain with the input signal power. The increase in the power of the input optical signal results in the decrease in the density of the carriers in the SOA. Due to this, the amplification gain of the SOA is also decreased. These dynamic processes taking place in the carrier density of the semiconductor optical amplifier are very fast (of the order of picoseconds). Thus it is possible to utilize this variation in the gain as per the bit to bit fluctuations of the input signal power. Figure 2.1 shows the operation principle of of a wavelength converter using XGM effect. There are two input data signals. One is low power continuous wave (CW) signal and the other is a pulsed signal. These two signals which are at different wavelengths are coupled to the SOA. When an input optical pulse appears on the pulsed signal, SOA gain decreases. This results in the continuous signal experiencing low amplification. On the other hand, if there is no light pulse on the pulsed input signal the gain of the device increases. This results in the CW signal experiencing high amplification. Thus incoming pulsed signal at λ_s is wavelength converted to $\lambda=\lambda_p$. The signal is inverted at the output.

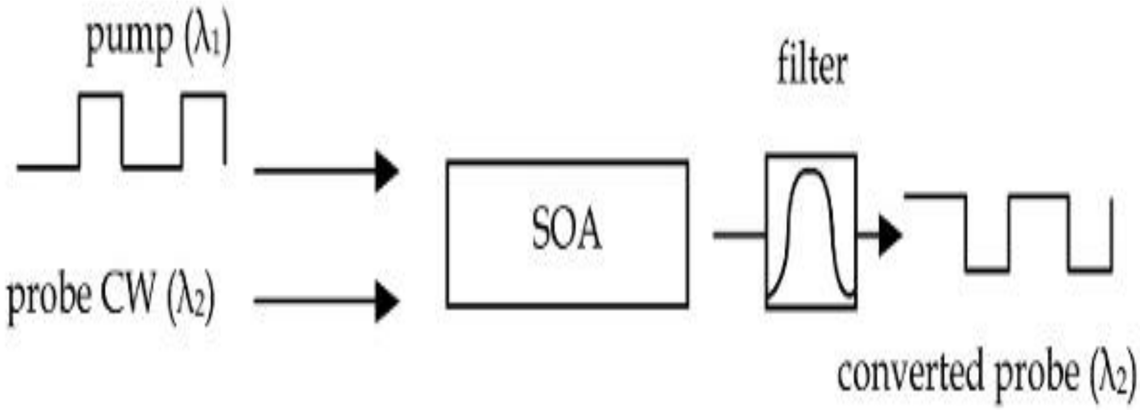


Figure 2.1: Simple wavelength converter using SOA –XGM.

High input signal powers (0 dBm) are required to deplete the carriers and there by saturate the device. Very good-shaped filters are required to filter the signal at the output of the device. As a result of the change of the carrier density, a change in the refraction index is also induced. This modulates the phase of the CW thus increasing the distortion of the output signal.

Many configurations are proposed in the literature utilizing this nonlinear effect. Several types of logic functions have been realized using cross gain modulation effect in the semiconductor optical amplifiers. These include AND, XOR and NAND Implementations.

2.3 Cross-Phase Modulation

The latter effect is the operation principle of XPM. The refractive index of the active region of semiconductor optical amplifier is not constant. It depends on the carrier density and hence the material gain. Thus phase and the gain changes of an optical signal travelling through the amplifier are coupled through the gain saturation. The amount of coupling depends upon the linewidth enhancement factor α. Wavelength converters and other functional devices can be created using XPM. As the XPM causes only phase changes, the semiconductor optical amplifier has to be put up in an interferometric configuration so that phase variations in the signals can be converted to the intensity variations using constructive or destructive interference. SOA is placed in the interferometer consisting of two identical branches. Both the continuous wave signal and the pulsed signal are coupled to both the branches. Symmetric optical couplers are considered having a coupling factor of α. In this way, the continuous wave signal is modulated in one side of the branch as a result of variations in the pulsed signal there by achieving constructive or destructive interference at the output. Figure 2.2 depicts the principle of operation. Signals are counter propagated in the interferometer. Phase information is converted intointensity information due to the interferometric arrangement. XPM based architectures generally use either a Mach Zehnder or a Michelson interferometric structure. . CPM can be used as a method for adding data to a light stream by varying the phase of a coherent optical ray with another ray through contacts in a suitable non-linear medium. This procedure is useful to fiber optic communications. In DWDM applications with intensity modulation and direct detection the influence of XPM is a two step process: Initially the signal is phase modulated by the copropagating second signal. In a second stage dispersion leads to a conversion of the phase modulation into a power variation. Furthermore the dispersion leads to a walk off between the channels and thus lessens the XPM effect.

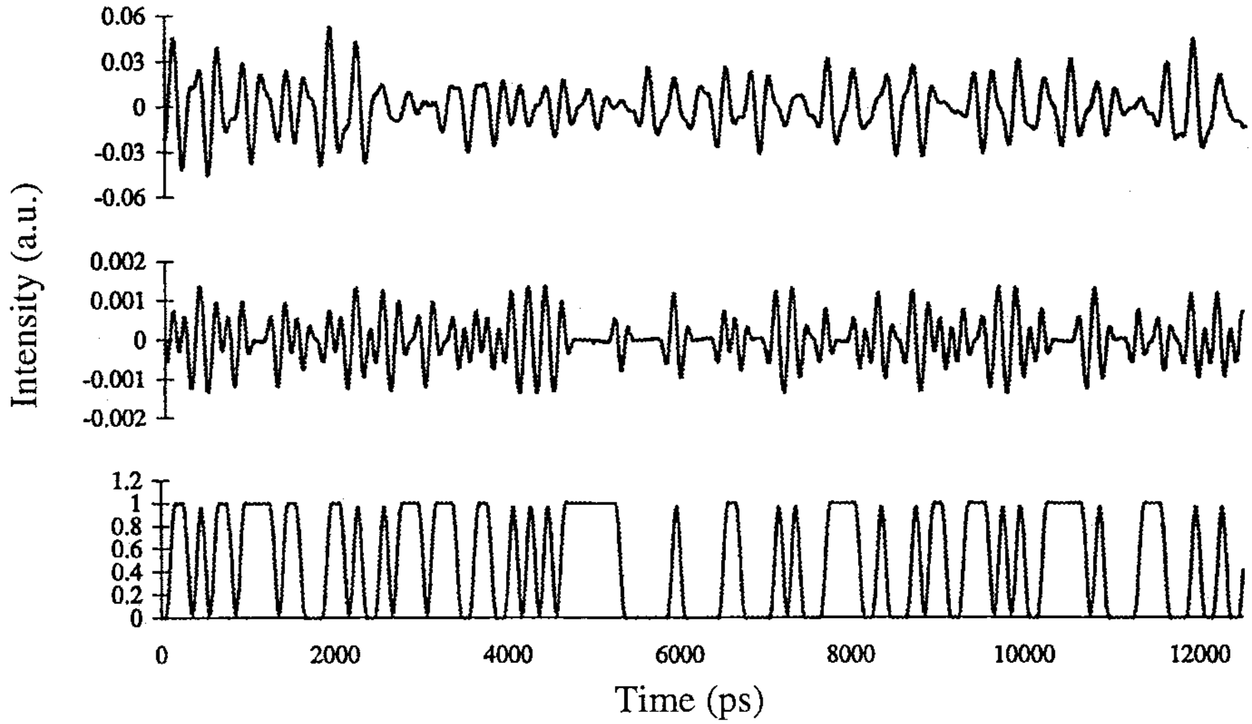


Figure 2.2: Wavelength converter using XPM in SOAs.

2.4 Four Wave Mixing

Four wave mixing is a nonlinear process, in which a new field gets created in a medium depending upon the product of three input electrical fields. In a semiconductor optical amplifier, gain and phase gratings are produced by beating of three input electric fields (at three different frequencies f1, f2 and f3). This results in scattering the input fields thus generating upper and lower sidebands. This results in generation of new frequencies at the output of the device. 2f1- f2 and f1+ f2- f3 are the combinations which will be at higher level. Four wave mixing effect is transparent to the data rate and the modulation format of the input optical signals. This is one of the main advantages of this nonlinear effect, as compared to XGM and XPM effects. At the other end, a filter is required for filtering out all the frequency components except the one of interest. The conversion efficiency becomes lower as the frequency difference between the input signals is increased. Thus high powers will be required at the input. FWM effect shows the polarization dependence. This effect is shown in

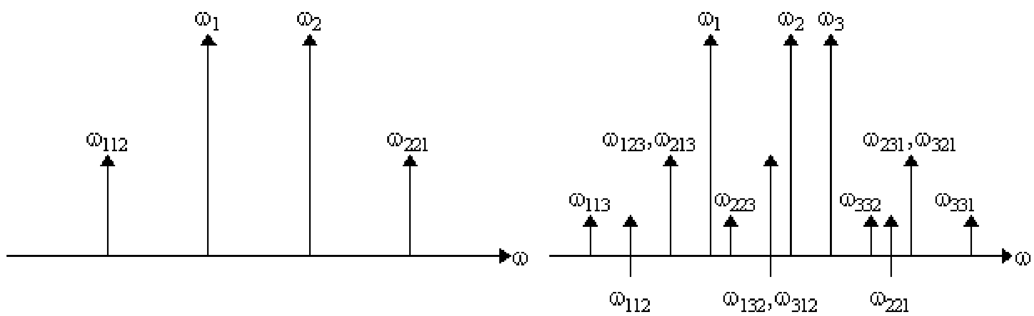


Figure 2.3: Application of FWM effect in SOA for wavelength conversion of input signal.

Beating of more than one frequency in the SOA causes new frequencies to appear at the output. A filter is there for filtering all the frequencies at output except the one of interest. FWM effect in SOAs can be used for realization of optical AND Gate .

2.5 Summary

The role and need of arithmetic and logic unit for optical computing and all optical processing in next generation optical networks is discussed. Semiconductor optical amplifiers are introduced and the basic principles of operation have been presented. Important all-optical configurations for implementing logic gates have been presented The fast non linear characteristics of semiconductor optical amplifiers are very attractive for applications in all optical digital processing such as optical Gates, flip flop, counter, registers square wave generation, adder, subtractor and comparator etc. As compared to the nonlinearity of optical fiber, implementations incorporating SOA have demonstrated great potential in terms of small footprint, high speed, optical integration and low power consumpti

Chapter 3

Literature Review and Outline

3.1 Introduction

There has been a growing interest in photonic digital processing for a long time. This is very promising in the application areas where fast computation speed is an important requirement. Short range optical interconnection networks represent one of these scenarios. The congestion in the chip to chip or memory to chip communication interface hampers the improvement of present day high performance computing systems. The limitations are imposed by the density of the wiring, throughput and the more power consumption. In these types of optical networks, optical digital signal processing could become the most suitable and efficient model for simple as well as ultrafast control and switching operations. This is due to the fact that it reduces the packet delay to the optical time of flight between the adjacent nodes. For applying optical digital processing for the purpose of controlling of various network operations, complex functions are required. All optical combinational circuits are essential for management of contentions and controlling the switching operation in the nodes of an optical packed switching network. Boolean numbers addition is a primary function to be performed in the header processing of packets. The other key components for these all-optical networks are alloptical regenerators, wavelength converters, all optical packet switches, and alloptical memory. All optical Gates, optical arithmetic and logic circuits and flip-flops form important subsystems of these components.

Optical logic gates with higher speeds are the main elements of the future generation optical networks as well as the computing systems. These are widely used to carry out all optical signal processing functions, such as binary addition, all-optical header recognition, parity checking, label swapping, and data encryption. A gate used to modulate a continuous wave (CW) signal can function as a wavelength converter. A gate used to modulate a pulse train can act as a part of an optical regenerator. Gates can also be used for time demultiplexing of input optical signals. Optical gates such as AND and XOR are used in routing functions.

SOA is very promising for the use in evolving optical fiber communication networks. This device exhibits various non-linear effects. Nonlinear effects make SOA a very interesting device for applications in optical networks. These nonlinearities can be used for ultra fast switching and gating applications. Optical logic functions may be implemented by employing nonlinear effects either in optical fiber or in SOA. Implementations utilizing SOA have shown great potential as compared to fiber based implementations. High speed, small footprint, low power consumption and potential for optical integration are the salient features of the device. As such, new ways to extend the data rates, simplify the structural configurations in order to improve the noise performance and potential for integration of present-day devices are constantly pursued. On the basis of above said issues the comprehensive literature review and gaps in present study are described in following Sections.

3.2 Literature Review For All Optical Logic Gates

Various approaches have been proposed in the literature to implement different types of logic gates employing nonlinear properties of SOA. These nonlinear properties include XGM, FWM, XPM and cross-absorption modulation in a semiconductor optical amplifier. A combination of these properties has als been utilized.

Kristian E. Stubkjaer reviewed the progress of logic gates. He reviewed the progress from simple logic gates utilizing XGM and FWM to the integrated interferometric gates using XPM effect.

Logic functions can be realized based on FWM in SOA. This is achieved by encoding information on the polarization of the input signals. By utilizing non return to zero PolSK signals, reconfigurable logic operations such as XNOR, XOR, NOR, AND can be obtained using four wave mixing effect at 10Gb/s. Zhihong Li et al. demonstrated different logic operations including XNOR, XOR, NOR, AND utilizng 10Gb/s NRZ PolSK signals.

The SOA-MZI can perform different types of optical logic functions with high extinction ratio at the output. This device needs low switching energy for operation and have compactness and regenerative capability. Reis C et al. experimentally demonstrated all optical XOR gates using SOA-MZI at 10 Gbit/s.

Ali Rostami et al. analyzed performance of an ultrafast all optical logic gate utilizing a quantum dot semiconductor optical amplifier. XGM effect is used for acceleration of the gain recovery process with the help of a control pulse

L. Li et al. demonstrated an all-optical reconfigurable logic gate utilizing FWM effect in a HNLF at 10 Gb/s. It utilized NRZ-PolSK signals. The input power to the highly nonlinear fiber is optimized to be as low as about 15.2 dBm. High Q factors above 8 dB are achieved for eye diagrams.

S.K.Garai et al. proposed a technique for optical realization of different logic operations based on frequency encoding method. Difference frequency generation and second harmonic methods ar used in a nonlinear material

S. Singh et al. proposed all optical logic gates including AND, OR, XOR, and XNOR atultrahigh speed by using SOA-MZI configuration. The simulations of optical logic gates are carried out at 40 and 120 Gb/s. Eye diagrams of proposed logic gates indicate a quality of more than 15 dB

Ehab S. Awad, P. Cho, and Julius Goldhar proposed high-Speed All-Optical AND Gate Using Nonlinear Transmission of Electron absorption Modulator in which Particularly,optical Boolean AND operation is indispensable to critical networking functions, such as header recognition , self-routing, switching, signal regeneration, and data encoding and encryption.

An all-optical logic scheme which exploits the cross-phase modulation (XPM) effect in semiconductor-optical amplifier-assisted Mach-Zehnder Interferometer (SOA-MZI), is proposed performance analyzed and parameters optimized. The proposal is validated and the system performance under various parameters is examined through numerical simulations. With only moderate parameters, high-speed all-optical AND gate based on SOA-MZI is realized with fairly high performance. The results are helpful for designing of SOA-based all-optical logic devices.

A.M Bastos et. al. [18] proposed an all-optical logic gate based on nonlinear slot-waveguide couplers. NOT, OR, and AND logic gates could be realized by using a single optical nonlinear directional coupler. Polarization dependencies of these waveguides were effectively utilized for realization of polarization-independent optical NLDC in the linear region and polarization-dependent all-optical switches in the nonlinear region. All the simulations were done for three-dimensional nonlinear waveguide structures by using numerical methods based on the full-vector finite-element method especially developed for nonlinear waveguides.

Xiujun He et. al. [19] studied the switching characteristics of asymmetric two core i.e. core 1 and 2 nonlinear fiber. This paper concludes that by using opposite sign switching efficiency is higher than using same sign of dispersion values. If efficiency of one core in fiber coupler is decreased the efficiency of same sign of dispersion values is higher. Meanwhile if the coefficient of two fiber was opposite than with same sign threshold power of one switch is lower than other. The paper concludes that asymmetric NLDC have high switching characteristics and low switching threshold power in comparison to Symmetric NLDC.

Prasanta Mandal et. al. [20] proposed a new method to construct all optical logic operation like OR and NAND based on nonlinear directional coupler. The optical switching could be achieved by Mach-Zehnder interferometer modulator. Effective switching was done by modifying the coupling length between the coupler waveguides with the help of an optical signal. As all-optical switching was used, a very high data rate could be achieved. Since NAND gate is a universal logic gate, any other logic gate can be realized using NAND gate.

Xiujun He et. al. [21] studied the switching characteristics and output coupling ratio of nonlinear directional fiber couplers (NLDC). In this paper input power and width of the input signal are discussed. Optical coefficient of soliton pulse is also discussed. The switching efficiency was improved by varying ratio of input and output power of core 1. Different output input matching ratio was obtained by varying gain of input cores 1 and 2. The gain could be changed by varying pump power of the optical amplifiers. Thus, variable fiber coupler with changeable output coupling could be made.

Gang Wang et. al. [23] proposed all-optical AND/XOR gates for non-return-to-zero (NRZ). In this paper expression of semiconductor optical amplifier used with Mach–Zehnder interferometers (SOA-MZIs) has been derived. The complementary data with the processed data was used to modulate the SOAs which could be used to reduce the patterning effects by accelerating rising and falling edges and increase the data rate to 40 Gbps. In the proposed AND gate, the SOAs were differentially biased to balance the phase in data bit '0'. The high output signal is obtained is superior for both AND/XOR gates and quality factor obtain is order of (Q > 6).

Yusheng Bian et. al. [24] theoretically realized all fundamental optical logic gates by using a multi-channel arrangement of functional units based on one-dimensional (1D) metal–insulator metal (MIM) structures. The working principle and necessary conditions for different logic functions were analysed and explained numerically by means of the finite element method. In contrast to most of the previous experiments that require multiple configurations to achieve different logic functions, a single configuration could realize all fundamental functions. It was shown that by giving optical signals to different input channels, the device could uses the logic gates such as OR, AND and XOR. By inputting signal in the control channel, more logic gates including NOT, XNOR, NAND and NOR could be realized. For these logic gates, between Boolean logic states "1" and "0" the intensity of high contrast ratio could be achieved at the telecommunication wavelength. The new all-optical logic device is simple, small in size and efficient. The proposed method could be applied to many nano-photonic logic devices, thus design is very useful for further development in on-chip optical computing.

Mehdi Tajaldini et. al. [25] proposed modal propagation analysis (MPA) as an important approach. In this paper work was done on multimode interference on small dimension. The finite difference method was used as a numerical method for solving the nonlinear modal equations and calculating the modal propagation constant. The characteristics of two initial modes show the changes that are introduced by nonlinear effects, in the direction of propagation the transformation of a sinusoidal profile changes to a Gaussian pulse, the increased oscillation of the induced phase, and variable wavelength shifting. Further, all these changes work differently for each mode. The Gaussian pulse combined with other observed phenomenon gives more efficient interferences among the modes and it show switching applications at a small Multimode interference. The steps for designing an optimum switch needs the implementation of a series of various evaluations of the switching operation based on linked parameters, such as the contrast ratio between the ON and OFF outputs, known as the performance gain of switch (SPG); this parameter was used to make the best switch through the width, and the power loss was used in the same way. The results indicated the multimode interference length scheme efficiency which is of approximate $10\mu m$ and that SPG depends on both output width and input intensity

A. Govindaraji [26] reported a numerical study of propagation of pulse and nonlinear directional coupler switching with the consideration of self-steepening effects and third order dispersion. The Split Step Fourier Method (SSFM) was used to plot th switching characteristics of nonlinear directional couplers by varying the third order dispersion and self-steepening values. The transmission factor was improved for lower values of third order dispersion at low input power but was deteriorated at high input power. It was observed that the energy transfer from one core to another is not occurred due to change in the shape of the input pulse.in super Gaussian due to change in pulse energy transfer occurred. The combined effect of TOD and SS further decreased the switching characteristics.

Qiliang Li et. al. [27] studied the behaviour of nonlinear directional coupler on all-optical logical gate in the presence of cross-phase modulation. OR gate, XOR gate and a new logical function based on nonlinear directional coupler, which can be used in transmission of signals in all-optical systems, were examined. Initially, the switching effect on pump power was evaluated. A pulse was imported into the nonlinear directional coupler and simultaneously a pump light was added using wavelength division multiplex in order to make use of Kerr effect and obtain XPM (cross phase modulation). The scenarios for the logical gate were analysed, and a switching characteristic curve was drawn via Matlab. Finally, the truth table was defined and it was clear that OR gate, XOR gate and a new logical function could be realized by changing the pump power. The study also indicated that by varying the input pulse's phase, switching could be realized. The truth table was again defined and it could be observed that different logic gates were realized.

J.S. de Almeida et. al. [28] presented a numerical expression of the transmission and switching of fundamental solitons in asymmetric NLDC. This asymmetric NLDC use dispersion decreasing fibers (DDF) that reduce the dispersion of the fiber. Two type of parallel fiber has been discussed here one which has reduced dispersion profile and another is constant profile. The extinction ratio are derived in this paper and conclude that it is 1.66 db for AND/OR logic gates. The truth table for AND/OR are also derived. Six different profiles of dispersion decreasing fibers (DDF): constant, exponential, Gaussian, hyperbolic, linear, and logarithmic were investigated.

Amir Mostofi et. al. [29] proposed coupling effect. Also describe the effect of coupling varied by using both dynamic and static in asymmetric NLDC with soliton switches. The effect is too strong near the switching region by using continuous wave. With the length of coupler effect kept increasing fast as double rate for linear coupling at odd multiple length i.e. $\pi/2$, in the case dynamic NLDC. In static soliton switching the effect is varied linearly that is bistability phenomenon occurs. At first bifurcation point, the effect is maximum. With no distortion of pulse or no emission of dispersive medium thevsoliton pulse is stable.

Nail Akhmediev et. al. [30] proposed two new families of coupled soliton in NLDC. The soliton pulse of new state with bistablity diagram has been discussed in this paper. In symmetric NLDC waveguide the bi-stability diagram for fiber coupler is same as for stationary wave. Physical reason behind this phenomenon has been discussed.

Zhongxi Zhang et. al. [31] describe a fourth-order Runga-Kutta. In order to solve the coupled NLDC Runga-kutta technique was applied. The birefringence of CNLSE is varied when light is propagated in the fiber. RK4IP includes error of computation by using CNLSE. RK4IP computation error is less in case of split step approximation. The step size of RK4IP could have the same magnitude as the dispersion length and the nonlinear length of the directional fiber, given the birefringence effect was less. For communication fiber couplers with random birefringence, the step size of RK4IP could be greater than the correlation length and the length that is above the correlation of the couplers, depending on the relation between linear and nonlinear effects. The general expression of local birefringence is also derived and the effect of kerr nonlinearities is considered. The RK4IP results conformed to those obtained from Manakov-PMD approximation.

M.S. Ismail [32] presented that the coupled nonlinear Schrodinger equation could model equation for optical fiber with linear birefringence. A finite element scheme was derived to solve this equation, this method was tested for stability and accuracy, and many numerical tests have been conducted. The scheme was of second order in both time and space dimensions and was highly stable. The scheme was quite accurate and efficient and described the interaction picture clearly. The derived method could be easily generalized to solve N coupled nonlinear Schrodinger equation.

Thiab R. Taha et. al. [39] described the nonlinear Schrodinger equations theory, applications and its limitation. In this paper different regimes are discussed in brief. The general expression for Parallel SSF methods is discussed. These methods were implementedon the Origin 2000 multiprocessor computer. The numerical experiments showed that these methods gave accurate results and considerable speed up.

There have been many other approaches for realizing optical logic [39], [40]. These include implementations based on single-mode Fabry-Perot laser diode or FWM effect in highly nonlinear fiber. For better clarity optical logic gates implementations based on different nonlinear effects

Chapter 4

Realization of All optical Logic Gates based on Nonlinear Properties of SOA

4.1 Introduction

All-optical logic functions are crucial elements in ultra-fast applications employing optical signal processing. Reconfigurable logic gates are mainly preferred as they are able to provide more flexible set of network functions. These functions include all-optical header recognition, label swapping, parity checking, binary addition, data encryption, time demultiplexing and routing functions .

There have been many approaches previously reported for realizing optical logic. Frequency encoding techniques using periodically poled lithium niobate (PPLN) waveguides do not have any problems concerning intensity loss. However the use of periodically poled lithium niobate waveguides make these implementations polarization and temperature sensitive . Proposals which are based on polarization based logic have certain disadvantages. The polarization state may change at the refracting and/or reflecting points along the propagation or transmission path length ,. As compared to the implementations utilizing optical fiber nonlinearity, the semiconductor optical amplifier based implementations demonstrate large potential as far as low power consumption, fast switching time, and optical integration is concerned . Semiconductor optical amplifier is an attractive nonlinear device, but SOA based realizations using two or more devices arranged in the interferometric configurations need accurate control and stabilization schemes . Logic gates employing FWM effect in semiconductor optical amplifiers suffer from polarization dependence and have low higher can be achieved with this device. This is possible with the help of using different interferometer structures or a continuous wave holding beam with high power. As a result of using these structures, the cost and complexity of the devices are increased. In this Section, an optical gate architecture is proposed to perform AND, OR and NOT logic functions using a single semiconductor optical amplifier. All optical logic operations are simple and reconfigurable and are implemented using RZ modulated signals at 40 Gb/s operational speed.

4.2. Principle of Operation

The all optical logic gates are implemented by FWM, XGM and XPM in semiconductor optical amplifier. Cross gain modulation is a non-linear effect that takes place in a semiconductor optical cavity for example SOA. This effect takes place when a high power input signal called Pump signal is injected into the semiconductor optical amplifier. This signal depletes maximum number of the carriersvwhich are present in the active region of the device when it is amplified. If simultaneously a lower power signal for example Probe signal is injected into the SOA, it will suffer attenuation due to the absorption of the carriers. In four-wave mixing effect two or three waves, co-propagating in the nonlinear medium (SOA), interact with each other generating waves at new frequencies**.** The cross phase modulation results due to chirps and large phase variation in the semiconductor optical amplifier with the ultra short injection of the pulse.

When two modulated, optical RZ control signals, along with the probe signal which is a continuous wave, are applied to the semiconductor optical amplifier, rising and falling edges of the probe are shifted towards shorter and longer wavelengths respectively . This occurs due to XGM and XPM effects in the SOA. These effects will result in the broadening of output optical spectrum of the probe signal as illustrated in Figure 4.1

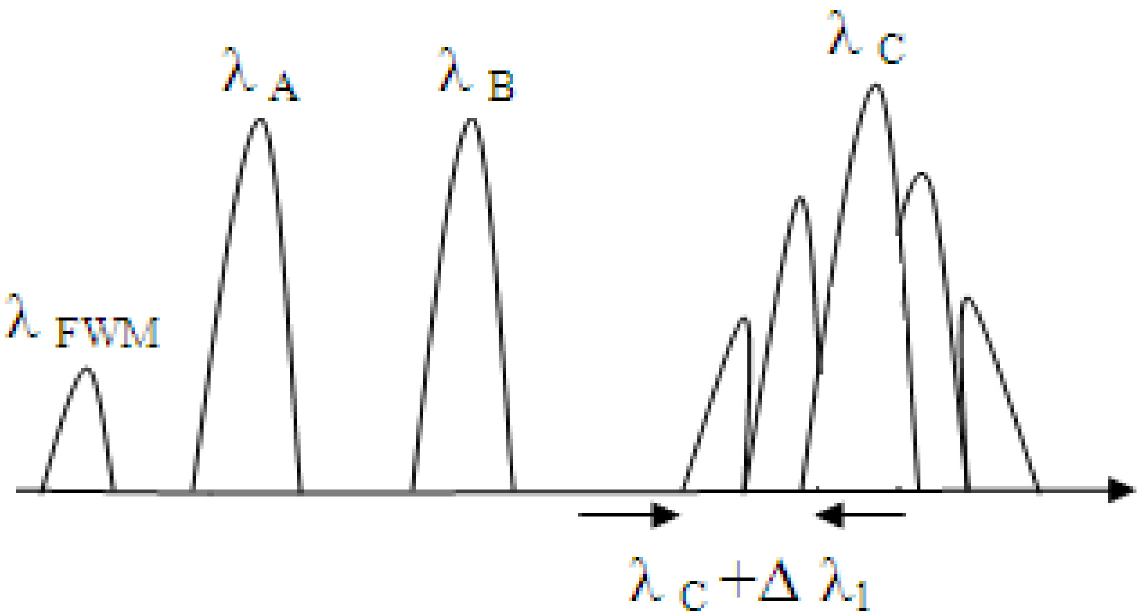


Figure 4.1: Conjugated light generated and broadened spectrum of the probe due to XGM, XPM and FWM respectively.

According to four wave mixing effect if f_1 is the frequency associated with the input signal and f_2 is the frequency of converted signal, the pump frequency is required to be chosen such that

$$\boldsymbol{f_p = f_1 + f_2 /2}$$

When two input data signals are applied to the semiconductor optical amplifier, the conjugated light is generated at the output as a result of four wave mixing effect as shown in Figure 4.1. This conjugated light generated is to be filtered out optically in order to generate AND logic. With the presence of data signals (*A* or *B)* or both, gain modulation of the probe signal takes place. This results in output which is polarity inverted, thus implementing a logic NOR operation. Thus NOR gate operation is obtained due to XGM in SOA. NOT gate operation can be obtained with the same filter detuning when only one data signal is present.

By shifting the optical bandpass filter‘s detuning by properly large value (i.e., $\lambda_c + \Delta\lambda_1$), probe carrier may be rejected thus selecting the part of the spectrum which is shifted. Either data *A* or data *B* or both the data signals applied to the semiconductor optical amplifier will be inducing the shift in the spectrum. If both the data signals are absent, there will not be any shifting of the spectrum. Thus the output will be logic OR gate. The truth table of the proposed logic gates is shown in Table 4.1.

Data A	Data B	OR	NOT A	AND
0	0	0	1	0
0	1	1	1	0
1	0	1	0	0
1	1	1	0	1

Table 4.1: Truth Table for all optical Logic Gates

4.3 Analysis And Methodology

The system configuration is depicted in Figure 3.2. The wavelengths of two CW beams generated by Laser Diode1, Laser Diode2 are 1549.3 nm and 1550.7 nm respectively

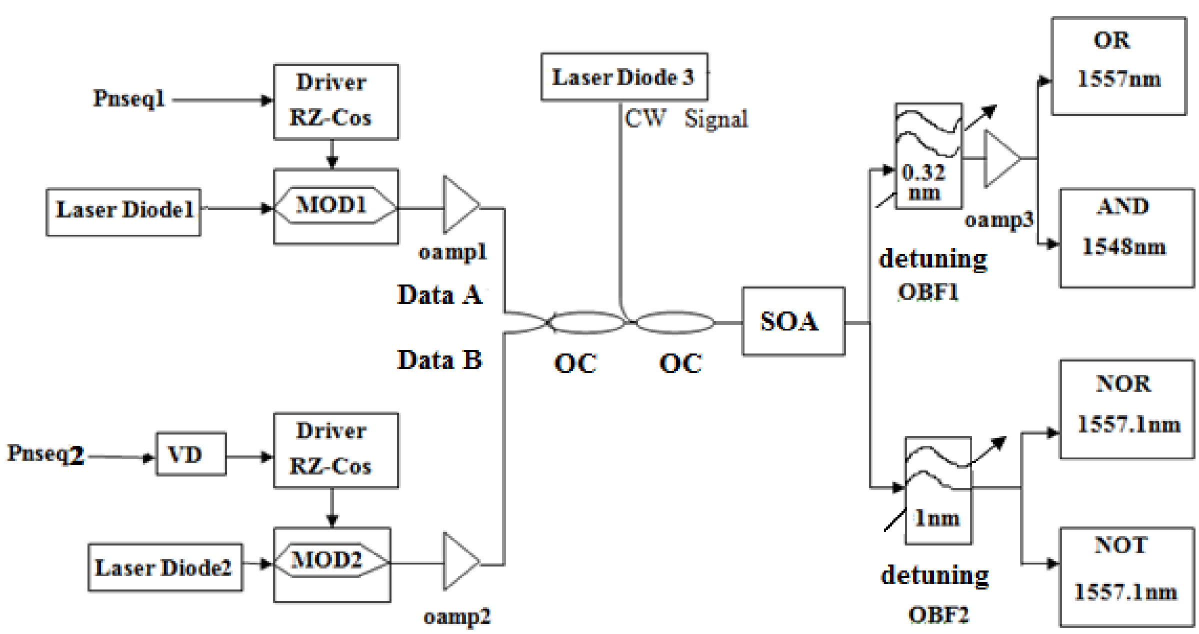


Fig 4.2 Numerical Simulation Setup

The configuration is depicted in the figure 4.2 .In this two continuous wave beams of different wavelengths is generated with the help of laser diode 1 and laser diode 2. Pnseq1 and pnseq2 generate pseudo random bit sequence. The data signals A and B are modulated at 40 Gb/s with the help of two modulators. Optical amplifiers oamp1 and oamp2 are used to amplify data signals. The probe signal (CW) is generated with the help of laser diode 3. SOA is biased at 300mA with line width enhancement factor of 6. The output of logic OR and AND gate is filtered with the help of tunable Gaussian narrow optical bandpass filter.

All optical logic functions are implemented based on the non linerities of semiconductor optical amplifire .With the proper adjustment of the parameters of semiconductor optical amplifire results into output signal whose power level is adjusted accordingly to generate different logic functions.

4.3.1 LOGIC NOT

XGM in SOA is used to obtain logic not gate output. When either the data signal *A* or datasignal *B* is present, the probe signal is gain-modulated. Hence a polarity-inverted output signal is obtained which results in logic NOT output.Due to limitation of cross gain modulation in semiconductor optical amplifire ,saturation appears in the output of logi not.Moreover due to this limitation the extinction ratio of logic nor gate is also very less.

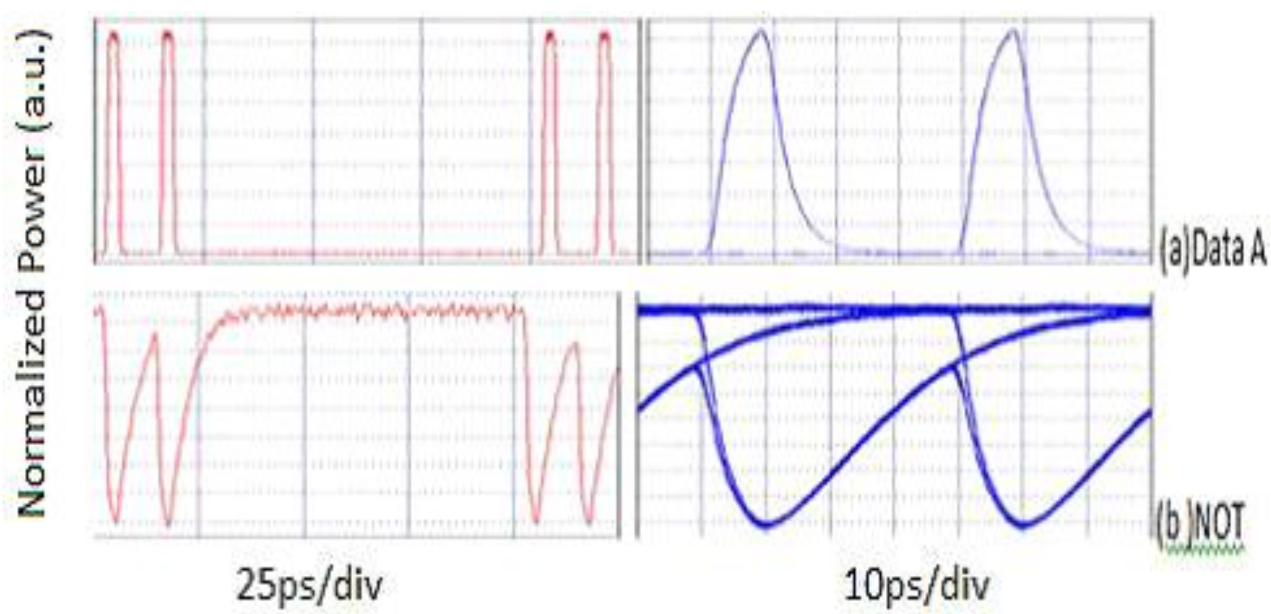


Fig 4.3: Output of logic NOT gate (a)Data A (b)Logic NOT

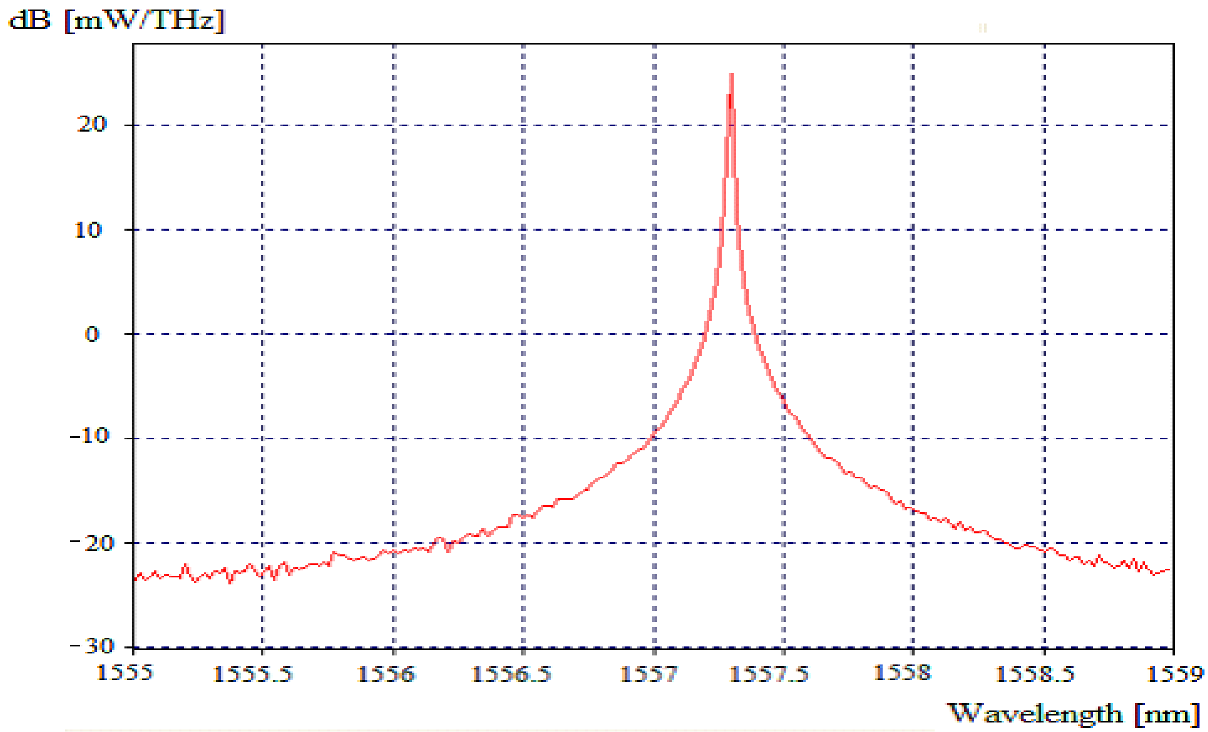


Fig 4.4 :Spectrum of probe signal before SOA

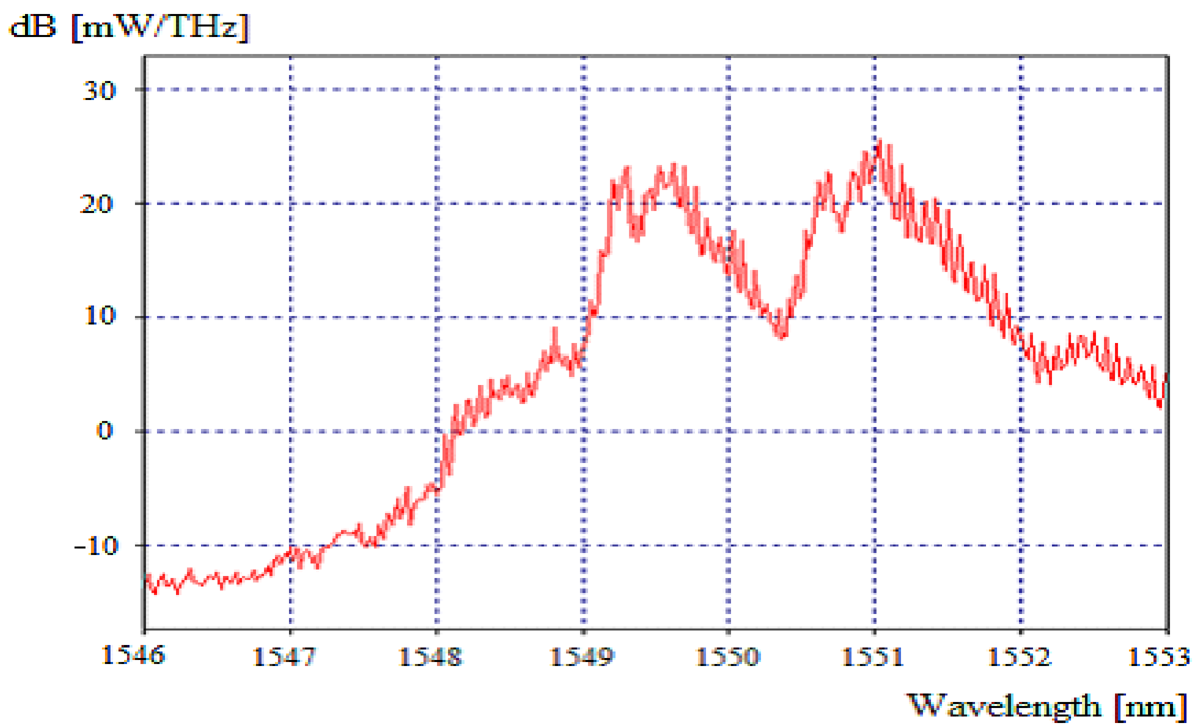


Fig 4.5 :Spectrum of probe signal at SOA output

4.3.2 LOGIC AND

Logic AND plays a very vital role in optical signal processing.FWM in SOA is used to obtain logic and gate output.In this logic ‘1’ is obtained when the both the data signa *A* and the data signal *B* is present at the same time.When either of the data signal is absent output logic ‘0’ is obtained.Due to limitation of four wave mixing effect the power level of output logic and gate is very less in comparison with not gate.The extinction ratio and contrast ratio of logic and gate is observed to be maximum.

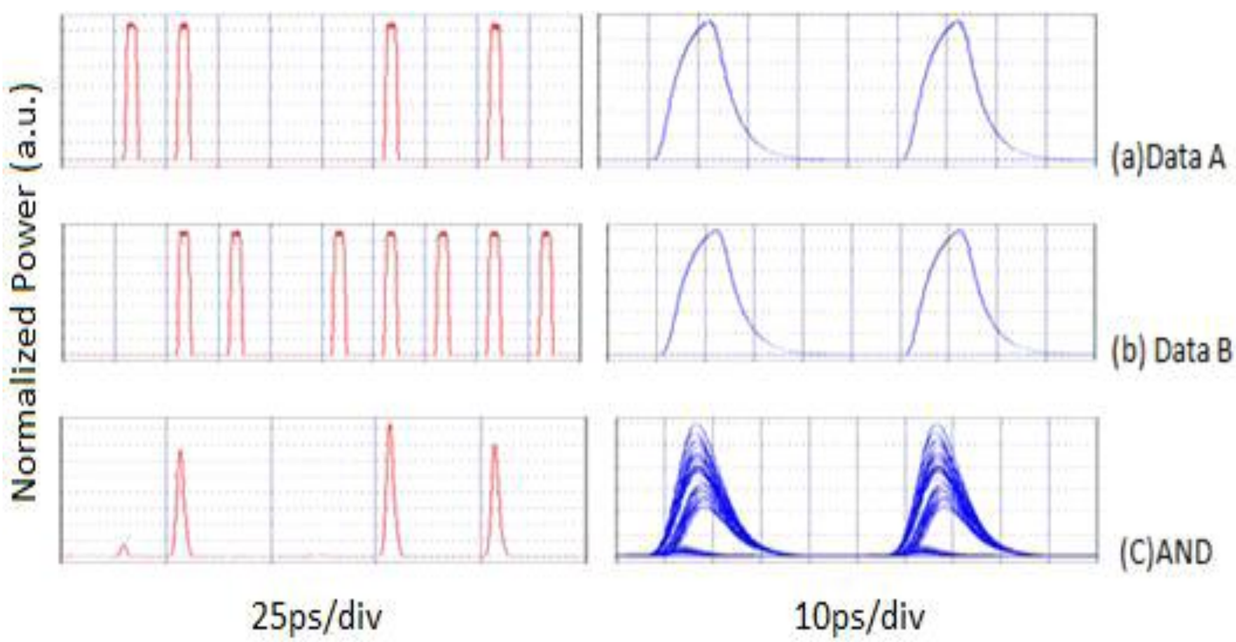


Fig 4.6 :Output of logic AND gate (a)Data A (b)Data B (c)Logic AND

4.3.3 LOGIC OR

When two data signals which are modulated with optical return to zero (RZ) modulation format along with a continuous wave probe signal are applied to the SOA, as a result of XGM and XPM, the optical spectrum of the probe signal at the output becomes broadened. A shifted spectrum is induced when either data signal *A* or data signal *B* or both the signals are applied to the SOA. In the absence of both the data signals, there will not be any shifted spectrum. OBF with properly large detuning select the shifted spectrum and rejects the prob carrier. Thus, logic OR gate is obtained at the output.

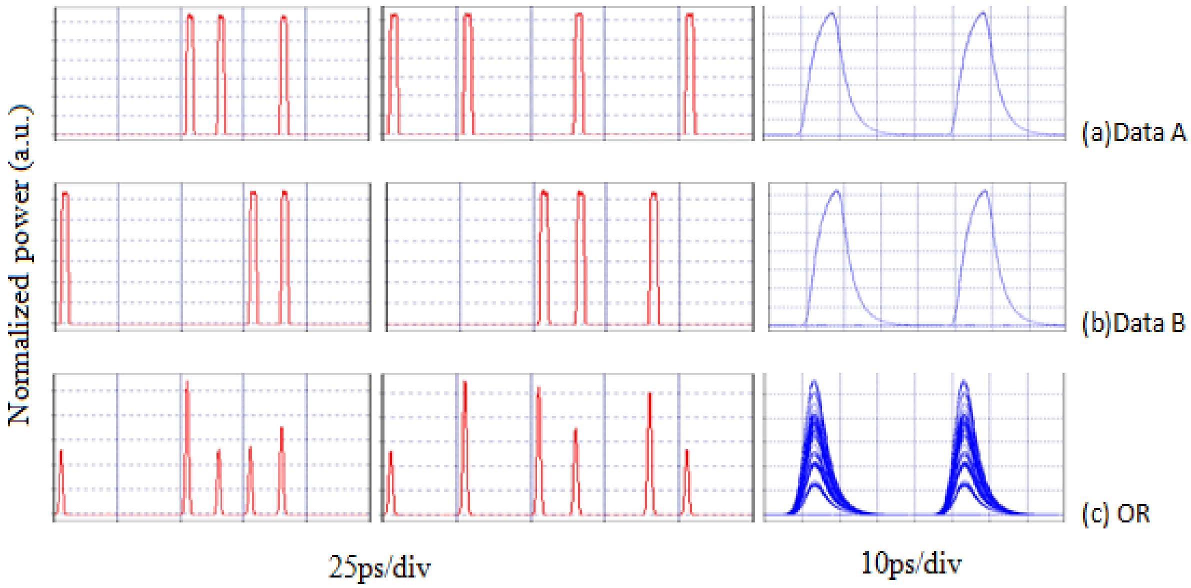


Fig 4.7 Output of Logic OR (a)Data A (b)Data B (c) Logic OR

4.4. RESULTS AND DISCUSSION

The all optical logic functions are obtained by FWM, XGM and XPM in a SOA. Simulation for output wave form is performed using RZ modulated signals, at data rate 40 Gb/s utilizing the parameters of semiconductor optical amplifier (shown in Table 4.2). Through the proper adjustment of the power levels at the input and the centre wavelength of OBF, different logic functions are realized.The performance of different logic gates is analysed with the help of its extinction ratio and contrast ratio.For good performance of logic gate its C.R and E.R must be very high.Higher contrast ratio shows the impact of input signal on output signal.Higher extinction ratio gives good distinguishes between logic level '0' and logic level '1'.Figure shows the graph of extinction ratio and contrast ratio with respect to variation in power level of input signals -3dbm to 3dbm. The extinction ratio obtained for OR, AND and NOT gates are 18.2dB,19dB and 9.7dB.

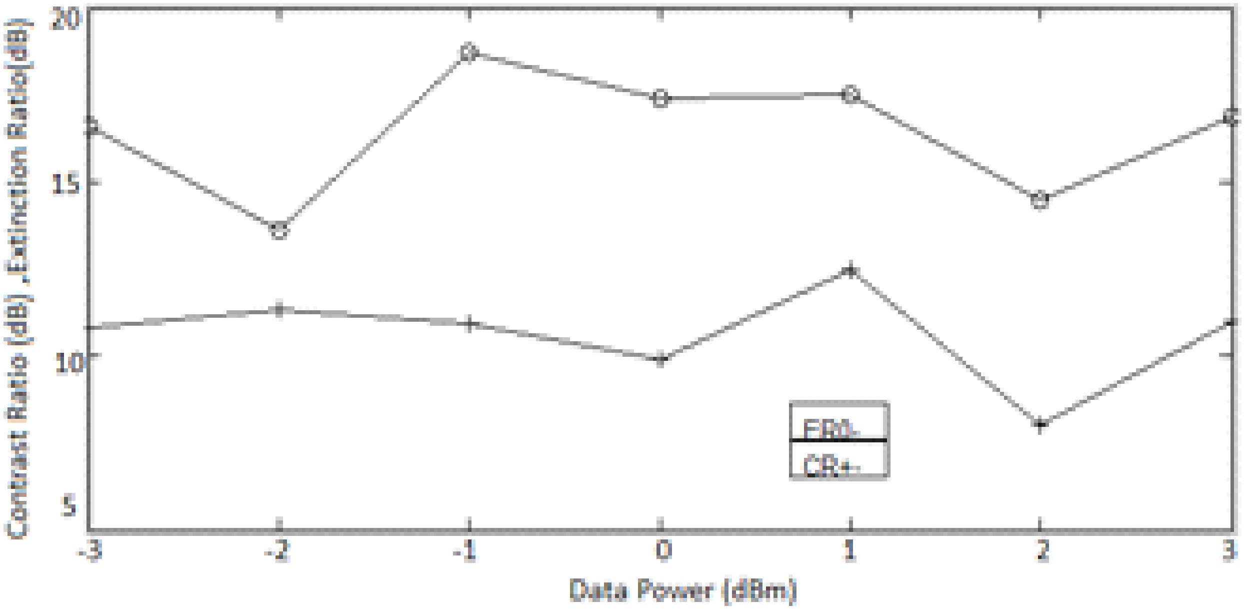


Fig 4.8 :Contrast Ratio and Extinction Ratio of logic AND gate.

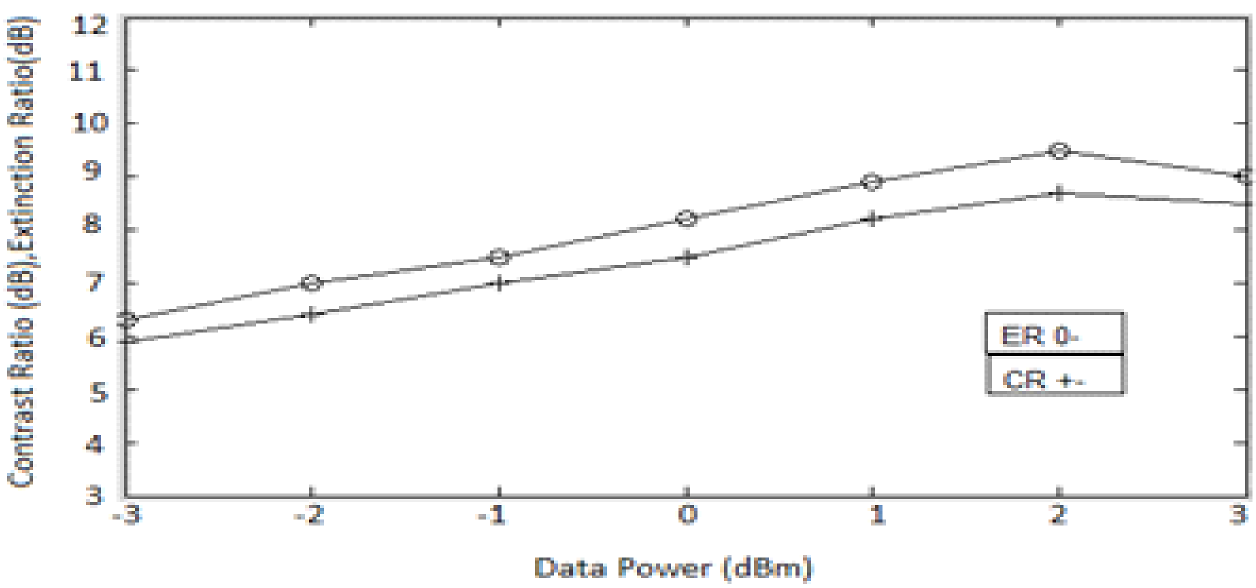


Fig 4.9:Contrast Ratio and Extinctio Ratio of logic NOT gate.

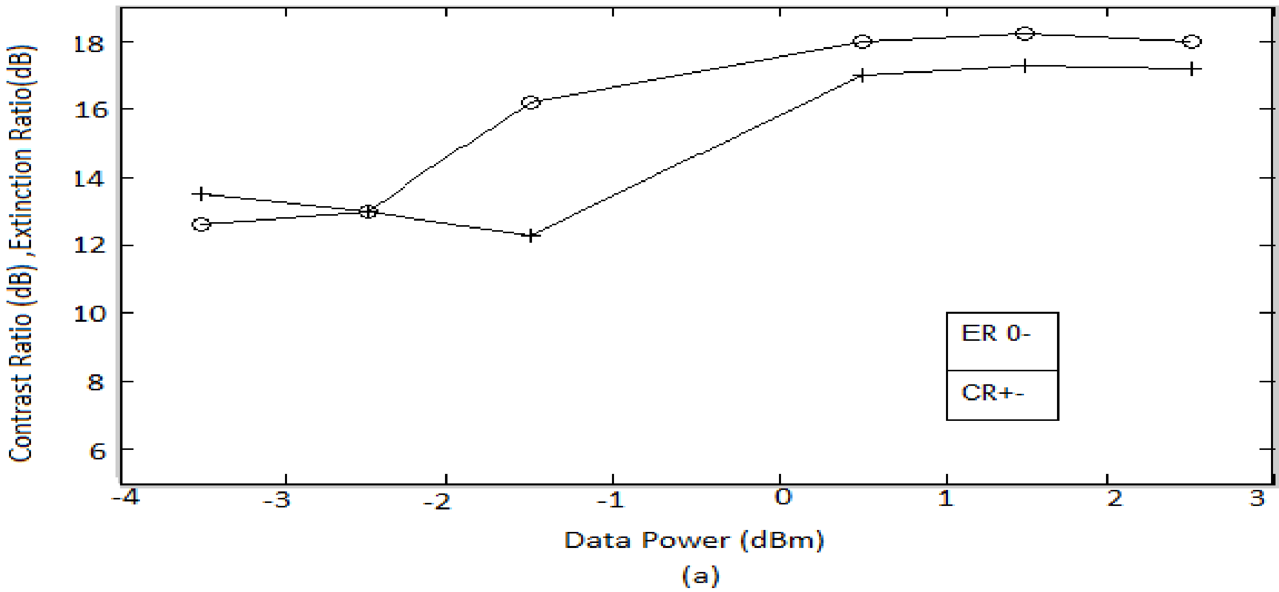


Fig4.10 Contrast ratio and extinction ratio of logic OR gate

CHAPTER 5

CONCLUSION

In this thesis an architecture is proposed for implementation of optical logic functions AND ,OR and NOT gate using the same design.All implemented logic operations are simple and reconfigurable Contrast ratio and extinction ratio has also been analyzed for the implemented logic gates.The maximum value of extinction ratio is found to be 19db and maximum value of contrast ration is 17.2 db which is quite accurate for logic gates applications. These devices have been investigated as they are integral components for optical computing and all optical processing in next generation optical networks. The proposed logic gates have a very simple structure and as they are based on the semiconductor technology allow for photonic integration.

Therefore, this study establishes designs and investigations of all optical arithmetic and logical devices which are very essential in the high capacity core networks in order to avoid opto electronics conversions and deal with the revolutionary growth of internet traffic for the future photonics networks

FUTURE SCOPE

1. Optical logic gates presented in this thesis have been realized at 40 Gb/s operational speed. As an immediate step forward, operation at higher bit rates, experimental validation at 40 Gbit/s should be carried out. The large amount of applications of Boolean gates has been commented within the contents of this thesis. One of the applications which show a special interest is the contention detection and resolution. Therefore, it would be interesting to study and design the architectures based on logic gates and switching devices (for example, flip-flops) that allow performing this task in the optical domain, without using electrical processing.

2. Modules of all optical logic gates are needed that are simple, polarization independent, reconfigurable and integrable. Moreover they should be able to operate at low optical power levels and be easily adjustabl to the system bitrate and transmission protocol.

References

[1] H. S. Hamza and J. S. Deogun, "Design and analysis of strictly nonblocking WDM optical switching networks," *Journal of Optical Networking*, vol. 6, no. 4, pp. 322- 340, 2007.

[2] P. K. Das, A. R. Pirich and A. Abbate, ―All-optical photonic devices,‖ In *proceedings of SPIE*, 1997.

[3] S am Darshi, R. Bhattacharjee, "Outage analysis of asynchronized wireless networks in interference limited environment," *IEEE Transactions on Vehicular Technolo*gy, vol. 62, no. 8, pp. 3863-3874, 2013.

[4] Y. Liu, E. Tangdiongga, Z. Li, H. deWaardt, A. M. J. Koonen, G. D. Khoe, X. Shu, I. Bennion, and H. J. S. Dorren, ―Error-free 320-Gb/s all-optical wavelength conversion using a single semiconductor optical amplifier,‖ *Journal of Lightwave Technolog*, vol. 25, no. 1, pp. 103–108, 2007.

[5] A. Shacham, B. A. Small, O. Liboiron-Ladouceur, and K. Bergman, ―A fully implemented 12 × 12 data vortex optical packet switching interconnection network,‖ *Journal of Lightwave Technolog*, vol. 23, no. 10, pp. 3066–3075, 2005.

[6] K.K.Bhattacharjee, F.C. Jain, ―Multiple quantum well acousto-optic and electrooptic modulators,‖ In *Proceedings of IEEE Conference on Ultrasonic Symposium*, vol.2, pp. 621-624, 1990.

[7] T. Houbavlis, K. E. Zoiros, M. Kalyvas, G. Theophilopoulos, C. Bintjas, K. Yiannopoulos, N. Pleros, K. Vlachos, H. Avramopoulos, L. Schares, L. Occhi, G. Guekos, J. R. Taylor, S. Hansmann, and W. Miller, ―All optical signal processing and applications within the Esprit project DO_ALL,‖ *Journal of Lightwave Technology*, vol. 23, pp. 781-801, 2005.

[8] Z. Li and G. Li, ―Ultrahigh-speed reconfigurable logic gates based on four-wave mixing in a semiconductor optical amplifier,‖ *IEEE Photonics Technology Letters*, vol. 18, pp. 1341-1343, 2006.

[9] Kristian E. Stubkjaer , ―Semiconductor Optical Amplifier-Based All-Optical Gates for High-Speed Optical Processing,‖ *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 6, no. 6, pp. 1428- 1435, 2000.

[10] J. Wang, G. Meloni, G. Berrettini, L. Pot`ı, and A. Bogoni, ―All optical clocked flip flops and binary counting operation using SOA based SR latch and logic gates,‖ *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 16, pp. 1486–94, 2010.

[11] J. Bernard and M. Renaud, ―Semiconductor Optical Amplifiers,‖ *SPIE ' s Optical Engieering Magazine*, vol. 1, no. 9, pp. 36–38, 2001.

[12] R. Steriti, J. Coleman and M. Fiddy, "A Neural Network Based Matrix Algorithm," in *International Joint Conference on Neural Networks*, San Diego, CA, USA, 1990.

[13] M. J. Connelly, "Semiconductor Optical Amplifiers,‖ Boston, MA: Springer- Verlag, ISBN 978-0-7923-7657-6, 2002.

[14] C. A. Khansa, S. Bhattacharya and A. Prabhakar, "Multiwavelength Er doped fiber amplifier," *Optics Communication*, vol. 282, no. 12, pp. 2380-2387, 2009.

[15] Anna Borghesani, "Semiconductor Optical Amplifiers for Advanced Optical Applications,‖ In proceedings of international conference on transparent optical networks (ICTON), vol. 1, pp. 119-122, 2006.

[16] D. H. Mynbaev and L. L. Scheiner, ―Fiber-optic communications technology, Pearson Education, 4th Ed., pp. 546-547, 2004.

[17] F. C. Jain and J. W. Marciniec, "A single-heterostructure MOS injection laser," *IEEE Journal of Quantum Electronics*, vol. 14, no. 6, pp. 398-401, 1978.

[18] C. F. Lam, Passive Optical Networks- Principles and Practice, Elsevier Science and Technology, 2007.

[19] B.Saleh and M.Teich, ―Fundamental of Photonics,‖ chapter 15 and 16, John Wiley Publisher, New York, 1991.

[20] G. P. Agrwal, ―Fibre-optic Communication Systems‖ third edition, Wiley, INC Publication, New York, 2002 (Chapter 3).

[21] G. P. Agrawal and N. K. Dutta, ―Semiconductor Laser,‖ 2nd edition, Van Nostrand Reinhold, New York, 1993.

[22] A. Bogoni, L. Poti, R. Proietti, G. Meloni, F. Ponzini, and P. Ghelfi, ―Regenerative and reconfigurable all-optical logic gates for ultra-fast applications,‖ *Electronics Letters*, vol. 41, no. 7, pp. 435-436, 2005.

[23] X. Huang, M. Zhang, L. Wang, and P. Ye, ―Novel scheme of 40 Gb/s all-optical NOT gate based on SOA-assisted Sagnac interferometer,‖ In *Proceeding of 2nd International Conference on Communications, Circuits and Systems*, Chengdu (China), vol. 1, pp. 621-624, 2004.

[24] S . A. Hamilton, and B. S. Robinson, ―40 Gb/s all-optical packet synchronization and address comparison for OTDM networks,‖ *IEEE Photonics Technology Letters*, vol. 14, no. 2, pp. 209-211, 2002.

[25] Y. N. Singh, H. M. Gupta and V. K. Jain, "Semiconductor Optical Amplifiers in WDM Tree-net," *IEEE Journal of Lightwave Technology*, vol. 15, no. 2, pp. 252- 260, 1997.

[26] S. H. Kim, J. H. Kim, B. G. Yu, Y. T. Byun, Y. M. Jeon, S. Lee, D. H. Woo and S. H. Kim, ―All-optical NAND gate using cross-gain modulators in semiconductor optical amplifiers‖, Electronics Letters, vol. 41, no. 18, pp. 1027-1028, 2005.

[27] J. Y. Kim, J. M. Kang, T. Y. Kim and S. K. Han, ―10 Gbit/s all-optical composite logic gates with XOR, NOR, OR and NAND functions using SOA-MZI structures, Electronics Letters, vol. 42, no. 5, pp. 303-304, 2006.

[28] M. Scaffardi, N. Andriolli, G. Meloni, G. Berrettini, F. Fresi, P. Castoldi, L. Pot`ı,and A. Bogoni, ―Photonic combinatorial network for contention management in 160 Gb/s interconnection networks based on all-optical 2 × 2 switching elements, *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 13, no. 5, pp. 1531– 1539, 2007.

[29] H. J. S. Dorren, M. T. Hill, Y. Liu, N. Calabretta, A. Srivastva, F. M. Huijskens, H. de Waardt, and G. D. Khoe, ―Optical packet switching and buffering by using alloptical signal processing methods,‖ *Journal of Lightwave Technology*, vol. 21, no. 1, pp. 2–12, 2003.

[30] F. Ramos E. Kehayas, J. M. Martinez, R. Clavero, J. Marti, L. Stampoulidis, D. Tsiokos, H. Avramopoulos, J. Zhang, P. V. Holm-Nielsen, N. Chi, P. Jeppesen, N.Yan, I. Tafur Monroy, A. M. J. Koonen, M. T. Hill, Y. Liu, H. J. S. Dorren, R. Van Caenegem, D. Colle, M. Pickavet, and B. Riposati, ―IST-LASAGNE: Towards all-optical label swapping employing optical logic gates and optical flipflops,‖ *Journal of Lightwave Technology*, vol. 23, no. 10, pp. 2993–3011, 2005. [31] J. Herrera, E. Tangdiongga, Y. Liu, M. T. Hill, R. McDougall, A. Poustie, G. Maxwell, F. Ramos, J. Marti, H. de Waardt, G. D. Khoe, A. M. J. Koonen, and H. J. 105 S. Dorren, ―160-Gb/s all-optical packet-switching with in-band filter - based label extraction and a hybrid-integrated optical flip-flop,‖ *IEEE Photonics Technology Letters*, vol. 19, no. 13, pp. 990–992, 2007.

[32] M. Scaffardi, P. Ghelfi, E. Lazzeri, and A. Bogoni, ―Photonic Processing for Digital Comparison and Full addition Based on Semiconductor Optical Amplifiers,‖ *IEEE Journal of Selected Topics in Quantum Electronics*, vol.14, no.3, pp. 826–833, 2008.

[33] Zhihong Li and Guifang Li, "Reconfigurable all-optical logic gates based on FWM in Semiconductor Optical Amplifier,‖ *IEEE Photonics Technology Letters*, vol. 18, no. 12, pp. 1341-1343, 2006.

[34] C. Reis, R. P. Dionisio, B. Neto, A. Teixeira, Andre, "All-optical XOR based on integrated MZI-SOA with co-and counter-propagation scheme,‖ In proceedings of international conference on transparent optical networks (ICTON), pp. 1-4, 2009.

[35] A. Rostami, H. Nejad, R. M. Qartavol, H. R. Saghai, "Tb/s Optical Logic Gates Based on Quantum-Dot Semiconductor Optical Amplifiers," IEEE Journal of Quantum Electronics, vol. 46, no. 3, pp. 354-360, 2010.
[36] L. Li, J. Wu, J. Qiu, B. Wu, K. Xu, X. Hong, Y. Li, and J. Lin, ―Reconfigurable alloptical logic gate using four-wave mixing (FWM) in HNLF for NRZ-PolSKsignal,‖ *Optics Communication*, vol. 283, pp. 3608-3612, 2010.

[37] S. K. Garai and S. Mukhopadhyay, ―A method of optical implementation of frequency encoded different logic operations using second harmonic and difference frequency generation techniques in non-linear material,‖ *Optik*, vol. 121, pp. 715- 721, 2010.

[38] S. Singh and Lovkesh, ―Ultrahigh speed optical signal processing logic based on an SOA-MZI,‖ *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 18, pp. 970–977, 2012.

[39] M. Uddin, J. Lim, Y. Jeong, and Y. Won, ―All-optical digital logic gates using single-mode Fabry-Perot laser diode,‖ *IEEE Photonics Technology Letters*, vol. 21, pp. 1468-1470, 2009.

[40] L. Li, J. Wu, J. Qiu, B. Wu, K. Xu, X. Hong, Y. Li, and J. Lin, ―Reconfigurable alloptical logic gate using four-wave mixing (FWM) in HNLF for NRZ-PolSK signal,‖ Optics Communication, vol. 283, pp. 3608-3612, 2010.

[41] U. K. Sengupta, U. H. Gerlach, S. A. Collins, ―Bistable optical spatial device using direct optical feedback,‖ *Optics Letters*, vol. 3, pp. 199–201, 1978.

[42] R. Clavero, J. M. Martinez, F. Ramos and J. Marti, ―All- optical packet routing scheme for optical label-swapping networks,‖ *Optics Express*, vol. 12, pp. 4326–4332, 2004.

[43] A. Bogoni, L.Poti, P. Ghelfi, M. Scaffardi, C. Porzi, F. Ponzini, G. Meloni, G. Berrettini, A. Malcarne, G. Prati,‖ OTDM-based optical communications networks at 160 Gbit/s and beyond,‖ *Optical Fiber Technology*, vol. 13, pp. 1–12, 2007.

[44] W.D'Oosterlinck, J.Buron, F. O¨hman, G.Morthier, R. Baets, ―All-optical flip–flop based on an SOA / DFB-laser diode optical feedback scheme,‖ *IEEE Photonics Technology Letters*, vol. 19, pp. 489–491, 2007.

[45] H. L. Minh, Z. Ghassemlooy and W. P. Ng,‖ All-optical flip–flop based on a symmetric Mach–Zehnder switch with a feedback loop and multiple forward set/reset signals,‖ *Optical Engineering*, vol. 46, no. 4, pp. 40501-03, 2007.

List Of Publications

1.Research paper titled "Design and Simulation of Optical Logic NOT and AND gate using SOA" published in International Journal of Advanced Research in Education & Technology.

2.Research paper entitled "Analysis of Performance Characteristics of different Optical logic gates"communicated in Microwave and Optical Technology Letters.

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