REVIEW ON $LINBO_3$ BASED EO-MZI FOR DESIGNING OPTOELECTRONICS DEVICES FOR WDM SYSTEMS

Arun G[1], Dr. A. S. Rathore[2], Dr.Sudhir N Shelke[3]

[1] Research Scholar, Department of Electronics & Communication Engineering, Sri Satya Sai University of Technology & Medical Sciences, Sehore, M.P.

[2] ResearchGuide, Department of Electronics & Communication Engineering, Sri Satya Sai University of Technology & Medical Sciences, Sehore, M.P.

[3] Principal, Guru Nanak Institute of Technology, Nagpur

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ABSTRACT:

The consistently rising demand for bandwidth makes it very difficult to grade electronic devices at these higher transmission rates, especially owing to their energy usage and power dissipation. Optics is a promising alternative for high-speed operations involving latch and memory components such as optical packet routing and ultra-fast computing. To achieve higher speed of data transfer, signal should be in the optical form. Semiconductor Optical Amplifier- Mach-Zehnder Interferometer (SOA-MZI) has played a significant role in the field of ultra- fast signal (optical) processing. In this article, review on $LINBO_3$ based EO-MZI for designing optoelectronics devices for WDM systems has been discussed.

Keywords:$LINBO_3$, EO-MZI, Optoelectronics, WDM

INTRODUCTION:

Many researchers have analysed the performance of SOA-MZI based switches and XOR gate through numerical simulations to generalize the optimal parameters as well as the suitable operation conditions (Zhang et al. 2003; Houbavlis et al. 2004; Han et al. 2008; Kotb et al. 2014). A Mach–Zehnder interferometric (MZI) wavelength converter consisting of integrated semiconductor optical amplifiers (SOAs) is utilized to implement all-optical modulation format conversion and divider circuit (Mishina et al. 2006; Aikawa et al. 2011).

The logic gates have potential to process or manipulate optical data at ultra-high speed (Gogoi et al. 2015) and suitable for wavelength division multiplexing (WDM). Various logic gate like NOR, NAND, AND (Ishizaka et al. 2011; Andalib 2009), OR, X-OR (Suzuki et al. 2009), and X-NOR gates are implemented by SOA-MZI and their performance is analysed experimentally (Zhang et1 al. 2003; Houbavlis et al. 2004; Aikawa et al. 2011; Kim et al. 2006; Mehra et al. 2013 a; Banaei et al. 2014; Bao et al. 2014; Chattopadhyay 2013; Dimitriadou et al. 2012 a, b, c). Digital systems consists of binary numbers that are used in almost all signal processing technique, routing, networking, data encoding/decoding and computers (Bhattachryya et al. 2012; Pal et al. 2016; Mehra et al. 2013 b).

Binary numbers can be represented as signed number (positive and negative). 1’s and 2’s complement are two methods to represent the sign number. Till now, 1’s and 2’s complement are implement using electronic logic device. As we know electronic devices (logic gates etc.) have some limitation like low switching speed, high power consumption and low operation bandwidth (Caulfield et al. 2010).

Conventional seven segment decoder having seven LED for showing the decimal digit 0 to 9. Each LED require around 20mA current for their operation, so one seven segment decoder requires 140mA current. It operates around 2 to 6 V and maximum operation is 20MHz. Electronic devices have speed limitation. The memory unit and an arithmetic and logic unit (ALU) are main components of any router, these are required for shortly accumulating the header intellect of a packet and processing respectively. Optical flip-flops (FFs) perform as the elementary unit (Liu et al. 2006; Jeong et al. 2006; Hill et al. 2004; Liu et al. 2010) for a memory element, and when networked with additional combinational circuits (Poustie et al. 1999; Cherri 2011), sophisticated devices for example shift registers, counters and RAM cells can be designed (Pleros et al. 2009). Various techniques like periodically poled LiNbO3 (PPLN) (Kumar et al. 2006), Erbium doped fiber amplifier (EDFA) (Maeda 1999) and Fabry perot laser diodes (FP-

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LDs) (Yoo et al. 2004; Nakarmi et al. 2011), have been used to design a number of combinational and sequential circuits.

However, these devices have limitations as well in case of PPLN based logic devices multiple light sources are required thus making them expensive (Kumar et al. 2006; Nakarmi et al. 2012). Whereas EDFA functions at low speeds upto 1 Gbps (Maeda 1999). Devices based upon FP-LDs are complicated due to the requirement of multiple FP-LDs and some additional devices to design simple logic circuit(s) (Yoo et al. 2004; Nakarmi et al. 2011).

REVIEW OF LITERATURE:

Chanderkanta et al., (2019) Power dissipation is an important consideration in digital design. Reversible logic is an unconventional form of computing in which the computational process is bijective and can efficiently reduce power dissipation problem. Peres gate is a basic reversible logic gate used in various reversible circuit. In this paper, design of Peres gate using electro-optic effect inside lithium-niobate based Mach-Zehnder interferometer is proposed. The various applications of Peres gate such as full-adder circuit and flip-flop is also explained. A theoretical description along with mathematical formulation of device is elaborated. The device is analyzed through Beam propagation method and MATLAB simulations

Presti, Damian et al., (2018)This work presents the design, development and characterization of an integrated optical modulator based on a Mach Zehnder Interferometer (MZI) recorded inside x-cut Lithium Niobate (LNB) wafers. These optical circuits were fabricated by means of femtosecond laser writing on LNB samples under planar configuration. Electro-optics modulation was achieved by adding metal electrodes on the LNB sample surface, configured as a coplanar strip layout. The latter fabrication procedure was conducted by using standard lithography and sputtering techniques from silicon platform. The MZI prototypes developed support single mode propagation at communication wavelengths (1.55 μm) and present a half wave modulation voltage, $V\pi$, close to 45 V measured with a bias unbalance between arms of 15 V. The MZI prototype has unique constructive features because it takes the advantages of the femtosecond laser writing. Additionally, it can be a key element of an opto-electronic device to be implemented in many systems, with high impact among others technological areas such as optical communication, sensing and control.

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Sweeney, Stephen & Mukherjee, Jayanta. (2017) Unlike the majority of electronic devices, which are silicon based, optoelectronic devices are predominantly made using III–V semiconductor compounds such as GaAs, InP, GaN, and GaSb, and their alloys due to their direct-band gap. Understanding the properties of these materials has been of vital importance in the development of optoelectronic devices. Since the first demonstration of a semiconductor laser in the early 1960s, optoelectronic devices have been produced in their millions, pervading our everyday lives in communications, computing, entertainment, lighting, and medicine. It is perhaps their use in optical-fiber communications that has had the greatest impact on humankind, enabling high-quality and inexpensive voice and data transmission across the globe. Optical communications spawned a number of developments in optoelectronics, leading to devices such as vertical-cavity surface-emitting lasers, semiconductor optical amplifiers, optical modulators, and avalanche photodiodes. In this chapter, we discuss the underlying theory of operation of some important optoelectronic devices. The influence of carrier–photon interactions is discussed in the context of producing efficient and high-performance emitters and detectors. Finally, we discuss how the semiconductor band structure can be manipulated to enhance device properties using quantum confinement and strain effects, and how the addition of dilute amounts of elements such as nitrogen and bismuth is having a profound effect on the next generation of optoelectronic devices.

Pal, Amrindra et al., (2017) Set-Reset (SR) latch or flip-flop is bistabile circuit. The circuit maintains a binary state indefinitely until directed by an input signal (clock signal) to switch state. Sequential logic circuits for specific application can be implemented by using SR flip-flop and external gates. In this article, SR latch and SR flip-flop is proposed using electro-optic effect inside lithium–niobate-based Mach–Zehnder interferometers (MZIs). The MZI structures have the powerful capability of switching an optical input signal to a desired output port. The article constitutes a mathematical description of the proposed device and thereafter simulation using MATLAB. The study is verified using beam propagation method (BPM).

Zhang and others (2016) By using an optical waveguide Mach-Zehnder interferometer made of x-cut lithium niobate and annealed proton exchange, we suggest an electro-optic mode switch. At a modest driving voltage, the device may change between the basic mode and the higher-order mode. When powered at a voltage of 1.7 V at 26 degrees C, our average manufactured device, which has a total length of about 24 mm, exhibits a mode extinction ratio of around 35 dB and a 20-dB bandwidth of about 12 nm at the wavelength of 1552 nm. Every wavelength in the C + L band may achieve high performance with a driving voltage variation of no more than 3 V. The suggested mode switch is simple to make and may be used in systems that allow for reconfigurable mode-division multiplexing.

Chen et al., (2015) An electro-optic tunable lithium-niobate (LN) waveguide Mach-Zehnder interferometer (MZI) is designed and fabricated with the annealed proton-exchange process. The MZI consists of a straight waveguide arm and a bent waveguide arm with a SiO_2 film deposited on the two sides. The residual stress generated by the SiO_2 film can enhance the index contrast of the bent waveguide arm and thus reduce the bending loss of the MZI. A comparison of several experimental devices fabricated on the same chip size of $50 ~{rm mm} times 7$ mm confirms significant reduction of the insertion loss by incorporating the SiO2 film. For our best sample, which functions as a tunable comb filter with a channel spacing of 0.75 nm in the C-band, the insertion losses of the two output ports are 13.5 and 6 dB, respectively, and the corresponding maximum extinction ratios are $sim 23$ and $sim 1.5$ dB. The device has an electrical wavelength-tuning sensitivity of $sim 0.2$ nm/V and a temperature sensitivity of $sim 0.1$ nm/°C. Our design approach can significantly improve the quality of LN devices that require waveguide bends.

Kumar, Santosh. (2015) An optical universal shift register (USR) has been demonstrated based on the electro-optic effect of lithium niobate (LiNbO3) in Mach-Zehnder interferometer (MZI), which can be used as a building block for optical computing and optical signal processing systems. The proposed device comprises of two serially connected optical D flip-flops and two multiplexers. Each optical D flip-flop consists out of three MZIs sharing a single clock pulse. The two cascaded multiplexers are controlled by the electric pulses in order to perform the bidirectional shifting and parallel loading operation of optical pulses. The pulse shifting behavior is analyzed using Beam propagation method (BPM) and verified with the help of MATLAB simulations and function table.

Bhatt, Gaurang et al., (2013) Integrated optical asymmetric Mach–Zehnder interferometer-based dense wavelength division multiplexing (DWDM) channel interleaver structures (2 x 2) have

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been theoretically studied using various single-mode waveguide geometries in silicon-on-insulator platform. Subsequently, a dispersion-free interleaver design has been proposed, fabricated, and characterized. It was designed to separate alternate DWDM channels with 100 GHz spacings. Some of the fabricated prototype devices have been fiber pigtailed and packaged in a suitably designed metal housing. The transmitted spectra (1520 nm <lamda<1600 nm) at each of the output ports reveal that alternate DWDM channel wavelengths are separated with a uniform inter-channel extinction of dB. Each of the channel passbands shows their 3-dB bandwidth of GHz.

Nazmi Mohammed (2012) The integrated Mach-Zehnder interferometer (MZI) at 1.3 m and 1.55 m is utilised in this research to construct electro-optic 22 switching devices that employ titanium (Ti) diffused lithium niobate (Ti:$LiNbO_3$) as a waveguide medium in the optical switch. Insertion loss and extinction ratio, two important design factors, are thoroughly examined and tested. Finding the ideal Ti strip thickness on MZI switches, which improves switching performance at 1.3 m and 1.55 m, is the originality of this study. In order to decrease total switch losses (0.0138 dB) and obtain the optimum extinction ratio (= 30 dB), the switch design parameters have been improved. The switch is extremely reliable and has a very high switching capability.

Mohammed et al., (2012) In this paper, the electro-optic 2×2 switching devices using titanium (Ti) diffused lithium niobate (Ti:$LiNbO_3$) as a waveguide medium in the optical switch is designed based on integrated Mach-Zehnder interferometer (MZI) at 1.3 µm and 1.55 µm. Two major design parameters; insertion loss and extinction ratio are evaluated and tested in details. The novelty of this paper is obtaining the optimum, Ti, strip thickness on MZI switch those results in improving switching performance at 1.3 µm and 1.55 µm. We have optimized the switch design parameters in order to reduce the overall switch losses (≤ 0.0138 dB) and to achieve the best possible extinction ratio (= 30 dB). The designed switch has a very high switching capability and a high degree of reliability.

Ab Rahman et al., (2010) The electro-optic 3×3 switching device using Titanium diffused lithium niobate or the Ti:$LiNbO_3$ as waveguide medium in the optical switch design based on Integrated Mach-Zehnder interferometer is investigated. The switching between the ports is achieved by an electro-optic effect within such structure. Voltage, applied to the electrodes

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deposited on the integrated Mach-Zehnder interferometer, creates an electric field distribution within the substrate, which consequently changes its refractive index. If properly designed, the induced change in the refractive index leads to different coupling between individual ports.

Ab Rahman et al., (2010) The influence of waveguide thickness on the output power according to the voltage applied to the electrodes based on Integrated Mach-Zehnder interferometer is investigated. Simulation result which are performed using BPM software, stress that there is an optimum value of 3x3 switching optical waveguide thickness at which the switch process and in turn the output power at 1300nm wavelength can be achieved. This is because the thickness affect significantly the coupling region between the waveguide, and also the effect of the Pockels and Kerr coefficients.

Lin et al., (2010) A bidirectional wavelength-division-multiplexing (WDM) transport system based on two reflective semiconductor optical amplifiers (RSOAs) and optoelectronic feedback technique is proposed and experimentally demonstrated. One RSOA is employed as a broadband light source and another RSOA in combination with optoelectronic feedback technique is used as wavelengths reuse and data signal remodulation scheme. System architecture is further simplified by using only one RSOA at the optical node, and system performance is further improved by optoelectronic feedback technique. Impressive performances of bit error rate (BER) (<;10⁻⁹) were achieved for both 2.5 Gbps down-link and 1.25 Gbps up-link transmissions.

Sohler et al., (2008) Various types of integrated optical devices have been fabricated in lithium niobate (LN), which has excellent electro-optical, acousto-optical and nonlinear properties. Optical channel waveguides of very low propagation losses have been fabricated through the use of the reliable technique of Ti-indiffusion. The inductively coupled plasma-reactive ion etching technique is optimized to fabricate 1.5 μm wide photonic crystal waveguides in a proton-exchanged surface layer of LN. Arrays of up to 101 coupled single-mode guides have been developed, which have led to peculiar properties for linear light propagation and have yielded new results for nonlinear propagation. Ring resonator is also fabricated in LN for rotation rate sensing with a diameter of 60 mm. It consists of a low-loss Ti:LN waveguide ring cavity and a straight waveguide tangential to the ring forming a directional coupler.

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Lifante and others (2007) We demonstrate integrated Mach-Zehnder modulators made on lithium niobate wafers with X- and Z-cuts. The Zn-diffusion approach was used to create the optical waveguides, which enables monomode TM propagation at the desired wavelength by selecting the channel waveguide width. It is demonstrated that the TM-mode is buried below the surface, eliminating the requirement for a dielectric buffer to lessen propagation losses brought on by the metallic electrodes used in electro-optic modulation. With Z-cut modulators with CCS arrangement, a switching volt-age-interaction length product of 9.2 Vcm has been measured; this value is somewhat higher than the theoretical value derived using the overlap between the externally supplied electrical field and the propagating optical field.

CONCLUSION:

Last few years have seen Semiconductor optical amplifiers (SOAs) and quantum dot as of interest by researchers and are used to model various combinational (Chattopadhyay 2011; Besse et al. 1997; Cherri et al. 2010) as well as sequential circuits (Stubkjaer 2000; Dimitriadou et al. 2013; Zoiros et al. 2011; Zoiros et al. 2000; Nady et al. 2013). The drawback with SOAs based designs is that these designs require interferometric structures that further necessitate several devices having matching characteristics as well as good control. For non-interferometric based techniques as suggested by Nakarmi et al. (2012) two additional beams and additional correlated components are required for realizing logic units.

Additionally, SOA based optical design requires high driving current and suffers from gain saturation (Stubkjaer 2000). The hunt for better features and Variables like immunity to electromagnetic interference, improved switching speeds (wider bandwidth), compact size, lesser weight, lower drive power, and above all compatibility with optical fiber keeps the research community motivated for finding alternatives to existing devices Electro-optic modulator (EOM) appears to be an appealing alternative as it meets all the above-mentioned parameters (Hunsperger 1995).

In an EOM, as the name suggests, an applied electric field varies the refractive index. The electro-optically induced index change transcribes into an electro optical phase shift in the guided mode. Generally, two sorts of mechanisms are utilized in EOMs. The mechanism usually used is the linear electro-optic effect (Pokel's effect), which causes real part of refractive index to vary linearly with applied electric effect. Another mechanism is the direct modulation of the attenuation coefficient for the optical wave via modulation of the imaginary part of the refractive index as implemented in electro-absorption modulators (Hunsperger 1995).

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