Design of 1x3 Optoelectronic Switch Based on MZI Structure
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Abstract—we present an electro-optic 1x3 switching device based on Integrated Mach-Zehnder interferometer made by Titanium diffusion in Lithium Niobate substrate. The switching between the ports is achieved by an electro-optic effect within such structure. Voltage, applied to the electrodes 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.

Keywords— Mach-Zehnder interferometer, Electro optics, Directional couplers, Switching voltage, All optical switch.

I. INTRODUCTION

Directional couplers consisting of two closely coupled waveguide are simple and essential elements in optical systems. In a modern communication network, switches are most important part of a network and in optical communication a switching in all light, means in optical domain is more important than switching in electrical domain i.e. conversion from optical to electrical and electrical to optical. With such a conversion the data transfer capability and speed of switching reliability is less. The speed of optical switches is necessarily has to match with currently new generation photonic devices in which light is not only carry information but also control the switching path is much important. The electro-optic effect is a change in optical properties of a material in response to electrical field that varies slowly with compared to frequency of light. One of the key elements that have many applications in optical wavelength division multiplexing and routing, are all optical switches. There are some of works in the field of optical switching based on directional couplers. In recent years various materials and configurations have been employed for the development of optical switches. For switching operation, some of mechanisms, such as thermo-Optic [1] and electro-optic [2, 3] can be used. But in optical communication, all-optical devices realizing high performance and speed are preferred. For applying the directional coupler to all- optical purposes, materials with high nonlinear characteristics are suitable. All-optical switches are desired devices in optical telecommunication. They can perform a variety of applications, particularly in single routing and time division signal processing. One of the major advantages of all-optical switches is that they avoid the need for optic-electronic and electronic-optic (o-e-o) conversions [2]. In spite of mentioned subjects, an electro-optic switch based on integrated Mach-Zehnder interferometer is required in many optical switching systems. To the best of our Knowledge, there is not any proposal for an electro-optic 3x3 switch based on integrated Mach-Zehnder interferometer that can work as switch. The proposed switch can have many interesting applications in optical telecommunication. Titanium diffused lithium niobate or the Ti:LiNbO3 waveguide is used as the waveguide medium in the optical switch design. The reason that of chosen this material is it has very low loss and switching voltage need to applied is small which is normally below 8V. In this work, we designed and simulated a new an electro-optic 1x3 switch based on integrated Mach-Zehnder interferometer. The device works based on electro-optic effects refer to changes in the refractive index of material induced by the application of an external electric field. The simulation of the structure is done using OptiBPM software. In the next section, we will present the design and simulation results and the paper will continue with conclusion, finally.

II. SWITCH DESIGN

We assume that the integrated switch is produced on a z-cut wafer Lithium Niobate, and is surrounded by air cladding. The device is targeted at the Y-axis optical Lithium Niobate. Therefore, we define a diffused material for the substrate and a dielectric material for cladding. The dielectric material chose is air with refractive index air n =1.0. The waveguides of Mach-Zehnder interferometer are produced by diffusion of Titanium in Lithium Niobate substrate. Just one diffused profile is required (Ti:LiNbO3). All switches device is 33 mm long and not more than 100 microns wide. The waveguide has a width of 8.0 µm Ti – diffused profile. The wafer has same refractive index like that of Lithium Niobate. The 3D wafer properties include air as a coating material with a thickness of 2.0 µm. It has Lithium Niobate as a substrate with a thickness of 10 µm. The device was created with the layout designer in th software optiBPM Optiwave provided as shown in Fig. 1
The RI profile of the XY slice was audited. The region of the electrode on the substrate also defined. We have created the electrodes on a buffer layer. The buffer layer has a thickness of 0.3 µm and a refractive index of 1.47. It has a horizontal and vertical permittivity of 4 and the electrode has a thickness of 4.0 µm. The three regions defined electrode has several design parameters. First region has a width of 50 µm and a voltage of 0.0 V. The second electrode region has a width of 26 micrometers and a voltage of 0.0 V. The third electrode region has a width of 50 micrometers and a voltage of 0.0V. The gap of 1-2 and 2-3 is equal 6.5. The second electrode has a central position of 5.3. The input plane has been selected with MODE like the starting field and 0.0 like Z-offset. After the input plane defined data set is MODAL refractive index and wavelength of 1.3 µm comprehensively. The 2D features have been put in TM polarization. Finite Difference scheme of engine parameters 0.5, the propagation step of 1.3 and TBC as a boundary condition. We calculated the isotropic 2D simulation. We varied the voltage electrodes for the Region 2nd. First the switching voltage of 0.0 V, then 7.0 V was checked. Further studies electro-optical switches have been using the scripting language [3]. When we run a simple scan script, we get a graphic representation of the optical field overlap in comparison to the number of iterations. It then became clear that the electro-optic switch is fully switching the total input signal from one output port to another for the second electrode voltage from -7.0V to 0.0V & from 0.0V to 7.0V.

Scripting: (using VB script)

ParamMgr.Setparam "V2",-7.0
For x = 1 to NumIterations
  ParamMgr.Simulate
  ParamMgr.Setparam "V2", 3.2*x
  WGMgr.Sleep (50)
Next

A nonlinear directional coupler includes three waveguides that have a small distance and fully coupling takes place between them in one coupling length. One of these waveguides or all have the nonlinear behaviour means, we can change the refractive index of nonlinear waveguide by applying a voltage between the electrodes, the three guides experiences an applied field E in opposite directions and hence experience opposite changes in their refractive indices. The corresponding switching voltage $V_0$ is [5],

$$V_0 = \frac{\sqrt{3} \lambda d}{2n^3 r L_0}$$

Where,

- $L_0$ = transfer distance, which is depends on the efficiency coupling $C$ between each two guides,
- $d$ = coupling separation,
- $n$ = refractive index of each guide which is equals, $r$ = the appropriate Pockels coefficient,
- $V_0$ depends on the refractive indices and the geometry of the guides. The coupling efficiency can be controlled by external voltage level applied through the electrode. The proposed structure for an electro-optic 1x3 switch based on integrated Mach-Zehnder interferometer is shown in Fig. 2.

![Figure 1](http://www.ijettjournal.org)

**Figure 1** A design of 1x3 optical switch of Mach-Zehnder interferometer without electrode region

<table>
<thead>
<tr>
<th>Output Port</th>
<th>Electrode-1 (W µm, V (V))</th>
<th>Electrode-2 (W µm, V (V))</th>
<th>Buffer Layer (W µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>26</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inter gap between 1st and center electrode: 5 (µm)</th>
<th>Inter gap between center and 2nd electrode: 5(µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrode thickness: 3 (µm)</td>
<td></td>
</tr>
</tbody>
</table>

A switching operation was achieved by properly changing the range of various parameters and set it as shown in table 1.
III. SIMULATION AND RESULTS

The complete design was stimulated in 2D using beam propagation method in Opti BPM Cad software. For simulation we set the global data with refractive index model and wavelength 1.3 micrometer. The 2D property has set with TM polarization, beam propagation method solver as a paraxial, engine with finite difference, scheme parameter 0.5, propagation step 1.5 and boundary condition TBC.[7]

![Figure 3](image3.png)
Figure 3 The output power vs. Iterations in each state according to the effect of changing the voltage 0.0V state 0

![Figure 4](image4.png)
Figure 4 The output power vs. Iterations in each state according to the effect of changing the voltage -7.0V state 1

![Figure 5](image5.png)
Figure 5 The output power vs. Iterations in each state according to the effect of changing the voltage 7.0V state 2

The applied voltage will determine the amount of optical power transmitted to a particular output port, and Fig.6 shows the output power vs. iterations according to the effect of changing the voltage. Mach Zehnder Interferometer can be used as active optical switch if a voltage is applied.

![Figure 6](image6.png)
Figure 6 A Powers in Output Wave Guides

The simulation results show good performance for this structure. Table 2 shows the insertion loss, and the extinction ratio of the proposed optical switch. Insertion loss of a switch is a part of power that is lost and has to be low for good performance and the extinction ratio is the ratio of output power in ON state to output power in OFF state.[5]

\[ \text{Insertion loss} = -10\log_{10} \left( \frac{P_{\text{out}}}{P_{\text{in}}} \right) \]  
\[ \text{[A]} \]

\[ \text{Crosstalk} = -10\log_{10} \left( \frac{P_i + P_j}{P_{\text{in}}} \right) \]  
\[ \text{[B]} \]

\( P_i, P_j = \) undesired output

<table>
<thead>
<tr>
<th>Switching State</th>
<th>Out Port</th>
<th>Insertion Loss (dB)</th>
<th>Cross talk (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>Port 1</td>
<td>0.96</td>
<td>6.77</td>
</tr>
<tr>
<td></td>
<td>Port 2</td>
<td>9.20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Port 3</td>
<td>10.45</td>
<td></td>
</tr>
<tr>
<td>Case 2</td>
<td>Port 1</td>
<td>15.37</td>
<td>9.91</td>
</tr>
<tr>
<td></td>
<td>Port 2</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Port 3</td>
<td>11.36</td>
<td></td>
</tr>
<tr>
<td>Case 3</td>
<td>Port 1</td>
<td>13.87</td>
<td>8.76</td>
</tr>
<tr>
<td></td>
<td>Port 2</td>
<td>10.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Port 3</td>
<td>0.65</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 7](image7.png)
Figure 7 A power overlap integral at all port of switch.

Table 2
Insertion Loss and Extinction Ratio of the proposed structure
As the biasing voltage from 0V to increase we can see that power decrease for port 1 and after 0V biasing voltage light propagate form port 1 to port 2 and port 3 switching is done. As the biasing voltage increase form ±3V power decrease and also coupling efficiency too. So for reliable switching we chose biasing voltage between ±7V to ±7V. The simulation results show good performance for this structure. The insertion loss (IL) [5] is the important parameter for the optical switching.

IV. CONCLUSIONS

The 1x3 Digital optoelectronics switch using mach zehnder structure has been designed and simulated in Opti-BPM for light switching to desired port by ±7V biasing voltage at 1300µm wavelength with TM polarization. Coupling efficiency of the 1x3 digital optical switch can be controlled by changing the electrode voltage. When no biasing voltage applied to electrode the coupling efficiency is almost equal to 100% and when biasing voltage applied the coupling occurs and by electro-optic effect we switch the light propagation to desired port. The future proposes work is to design a switch for high wavelength and independent polarization i.e. both TM and TE polarization with less losses. With this electro-optic effect, the 1x3 optical switch can act as an electro-optic switch to switch optical signal to desired output port.

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