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ARTICLE

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THEORETICAL ANALYSIS OF CHIRAL MACH-ZEHNDER INTERFEROMETER BASED ALL-OPTICAL LOGIC GATE

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In this communication, we have theoretically analyzed the design of a Chiral Mach-Zehnder Interferometer (CMZI) based all-optical switch which can perform multifunctional logic operations. Here, we have placed a chiral material on the upper arm of the interferometer to produce the necessary polarization rotation and utilized the port-II which makes this design very efficient and promising. Numerical simulation using SCILAB has also been done to visualize the performance of the or logic.

Introduction

In this era of modern digitization, there is a promising voice of success for optical communication over electronic communication. In any optical communication and information processing system, optical switches are the cornerstones. The demand of an all-optical switch with ultra-low power, ultra-fast switching speed and having greater extinction ratio is increasing day by day but it is remarkably challenging as well.

To obtain all-optical switching, different methods and devices have been established e.g, SOA-based all-optical polarization rotation switch[1-3], Reflected Semiconductor optical Amplifier (RSOA),[4], Nonlinear Optical Loop Mirror (NOLM)[5,6], Mach-Zehnder Interferometer (MZI)[7,8], Terahertz Optical Demultiplexer (TOAD)[9,10]. Micro Ring Resonator (MRR)[11,12] etc. Out of them, Mach Zehnder interferometric circuits are highly recommended for its useful advantages.

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In their paper, Ruan et al experimentally reported a chiral Mach-Zehnder interferometer (CMZI) based switch that consumes very-low power (1.3±0.1fJ/bit) and realizes high bandwidth (4.2GHz) [13]. However, only one of the ports i.e port-I was utilized in that design and signal coming out from the port II (i.e. lower output port) remained unused. But, in this work, we have made slight modification by incorporating a vertical polarizer in port –II. In our modified design the port-II of chiral Mach-Zehnder interferometer-based switch performs the all-optical logic OR operation.

The Principle of Operation of All-optical Switching

The principle of operation of the all-optical switching module has been demonstrated along with the schematic circuit diagram (Fig.1). Here, we have utilized the optically active chiral material such as quartz at the upper arm of the interferometric switch of proper length, by virtue of which we achieved the desired rotation in polarization.

Now, we will realize the following truth table.

Probe signal	Control Signal	Output Signal
0	0	0
0	1	1
1	0	1
1	1	1

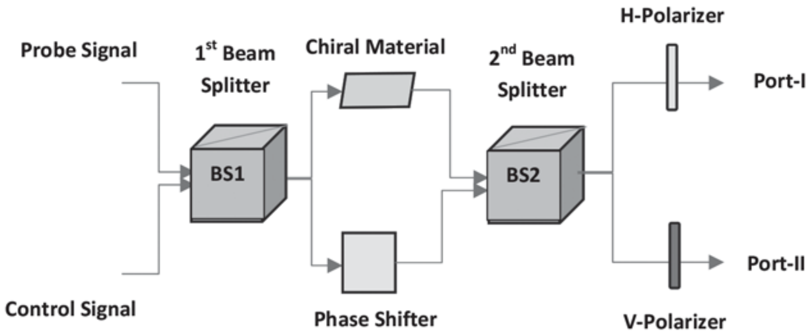

Fig.1. The Schematic circuit diagram of all-optical Chiral MZI Switching module

When there is no probe and control signal, the output at port-II will be zero.

Then, in the absence of a probe signal, if there is a V-polarized control signal, a V-polarized light comes out from the 1st beam splitter which passes through the chiral material at the upper arm and interestingly turns into an H-polarized light. Thus, a V-polarized light which only faces a phase shift from the phase shifter at the lower arm and the H-polarized light at the upper arm will superpose into the 2nd beam splitter and from which a (H+V) polarized beam emerges at both arms. A V-polarizer is finally used to receive the output at port-II.

Again, if a H-polarized probe signal is present but there is no control signal, a (H+V) polarized beam will be found after the 2nd beam splitter at both the arms in the similar fashion as discussed above. Therefore, the final output that will be received at port-II is V-polarized.

Finally, when an H-polarized probe signal and a V-polarized light control signal both are present, an right circular polarized (RCP) light emerges from the 1st beam splitter at the upper and lower arm respectively. The chiral material will retain the state of polarization of the RCP light and only produce some phase shift. Due to the constructive interference at port-II, we will receive a high-intensity V-polarized output there.

Hence, we can visualize that the output at port-II follows the truth table of OR logic operation.

Theoretical Framework

In presence of the vertically polarized control signal, the equation corresponding to the output intensity at Port-II, can be written as [13]

$$I_{ON}^{(\lambda)} = \frac{I_0}{4}\left[\eta_1 + \eta_2 + 2\sqrt{\eta_1\eta_2}\,\cos\left(\frac{2\pi\nu}{c}\,\Delta L\right)\right]$$

But, in the absence of the control signal, the intensity of the output signal at port-II will be,

$$I_{OFF}^{(\lambda)} = \frac{I_0}{8}\eta_2$$

Where, I_0 is the total intensity of the input signal. The total effective transmittances at the lower and upper

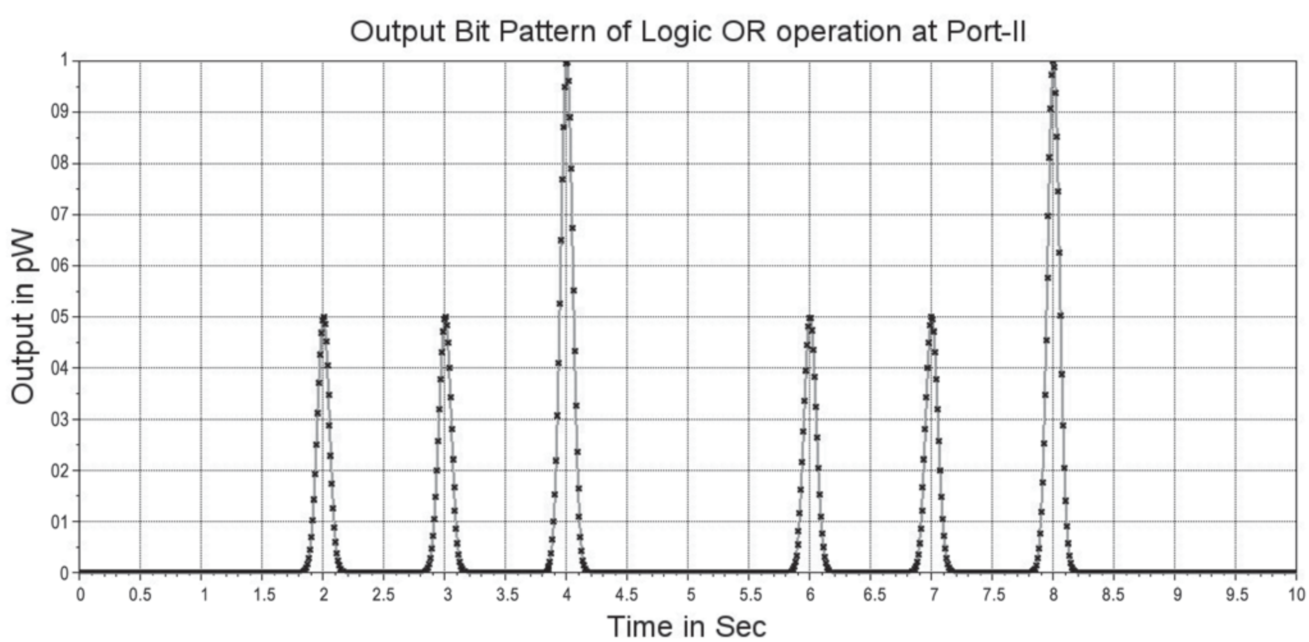

Fig.2. Output Bit pattern of logic OR operation at port-II

arms are η_1 and η_2, respectively. ΔL is the effective optical path difference which causes the resulting phase shift, ν be the frequency of the input signal and C be the velocity of light in vacuum.

Simulation and Result

To understand the logic OR operation at the 2^{nd} port of this all-optical chiral based MZI, we obtain the bit pattern using SCILAB simulator, from which quality factor (Q-value) and amplitude modulation (AM) have been calculated.

Here, we put the experimental values of transmittances and frequency of the input signal as[13],

$\eta_1 = 0.98$ and $\eta_2 = 0.82$ and $\nu = 384.2793$ THz.

Here if we assume that, 0 to 0.2pW as 'LOGIC 0' and 0.4 to 1.0 pW as 'LOGIC 1' then it is clear from figure-2 that the bit pattern (0111 0111) follows the truth table of an OR gate which is given below.

Here, $1_{max} = 1.0$ pW and $1_{min} = 0.5$ pw.

Thus, the calculated value of amplitude modulation (AM) = $10 \log_{10}(1_{max}/1_{min}) = 3.01$dB and Q-value= 2.8001 dB.

Conclusion

In this paper, we have reported the theoretical framework along with the numerical simulation of all-optical chiral Mach Zehnder interferometric switch that can utilize both the ports of the CMZI. Port-II performs the logical OR operation and the output bit pattern (8-bit) at Port-II is obtained using SCILAB and AM & Q-value are also calculated which reflects that there is a need of modification to improve the circuit efficiency. ❒

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