AN ALL-OPTICAL POLARIZATION ENCODED XNOR LOGIC GATE

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Abstract: Optical logic gates are the building blocks of an optical computing system. Here, a polarization encoded 2-input optical XNOR logic gate is proposed. The proposed scheme can have a strong application in all-optical computational system.

Keywords- XNOR; logic gate; Kerr effect; nonlinear material; polarization; binary;

1. Introduction

The endeavour for implementing all-optical computational system was started few decades ago [1]. Optical signals have been used since then in computation as well as in communication. This is because optical signal has many inherent advantages. Different techniques and materials have been used for implementation of such optical systems. In some proposals semiconductor optical amplifier was used to develop optical logic gates [2, 3]. Some optical logic gates were reported based on micro-ring resonators [4, 5], Mach-Zehnder interferometers [6] etc. Again, optical nonlinear material was used in many reports for developing optical systems [7,8]. Optical Kerr type nonlinear materials played a crucial role in the development of optical computing systems [9].

For the construction of these optical systems several encoding-decoding techniques have been proposed. Among these techniques, polarization-based encoding-decoding technique is a convenient way of representing the optical binary data signals. In this method a light beam polarized perpendicular to the plane of paper (●) is considered as ‘logic 0’ state and the light beam polarized in the plane of paper (↕) is assumed as the ‘logic 1’ state. Many works have already been reported where this type of encoding-technique was used [10, 11]. Optical XNOR logic gate is an important component for an optical computing system. Here in this communication, an optical XNOR logic gate has been proposed using the polarization-based encoding-decoding technique and optical nonlinear material.

2. Materials and method

2.1. Optical nonlinear material

In Kerr type of optical isotropic nonlinear materials (NLMs) the second order nonlinearity is prominent. Due to this reason the refractive index of the material changes with the intensity of the light passing through it. The refractive index of this type of materials is given by

$$n = n_0 + n_2 I$$

In the above equation, ‘n_0’ is a constant linear term and ‘n_2’ is a nonlinear term and ‘I’ represents the intensity of the light signal passing through the material. As refractive index changes with the intensity these materials can act as a switch.

A light beam PQ (assumed to be of a prefixed intensity ‘I’) is incident on the linear material (LM) and nonlinear material (NLM) block [fig.1]. The beam QR after passing through the LM incident at the boundary of the LM and NLM. This beam is now refracted as the beam RT and collected in the channel ‘Y_1’.

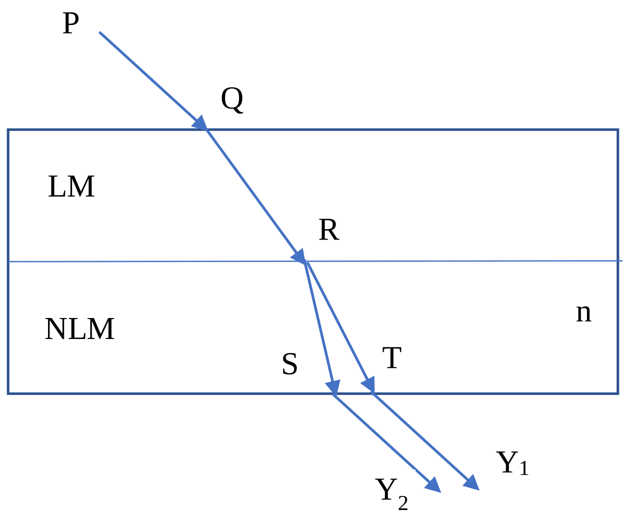

Fig.1: Optical nonlinear material used as a switch

Now, if the intensity of the incident light beam PQ is increased to '2I' (or any prefixed value) it again passes through the LM as the beam 'QR' because the refractive index of the LM is same as before. But the refractive index of the NLM is now changed as the intensity of the beam has been changed. So, the light beam is now refracted as RS and is collected in the channel 'Y_2' instead of the channel 'Y_1'. Thus, the NLM can be used as an optical switch.

2.2 Polarization-based encoding and decoding technique

In this technique binary 'logic 0' (low state) is represented by a light beam polarized perpendicular to the plane of paper (●) and 'logic 1' (high state) is represented by the light beam polarized in the plane of paper (↕).

3. Result

Polarization encoded optical 2-input XNOR logic gate

The truth table of the optical 2-input XNOR logic gate is shown in the 'table-1' and the proposed scheme is shown in 'fig.2'.

Table 1: Truth table of 2-input XNOR logic gate

Input		Output
A	B	$Y = A.B + \bar{A}.\bar{B}$
0 (●)	0 (●)	1 (↕)
0 (●)	1 (↕)	0 (●)
1 (↕)	0 (●)	0 (●)
1 (↕)	1 (↕)	1 (↕)

4. Discussion

The proposed scheme is shown in 'fig-2'. Here, 'P_1' and 'P_2' are polarizers which can pass only light signals polarized perpendicular to the plane of paper (●). The polarizers 'P_3' and 'P_4' can pass only light signals polarized in the plane of paper (↕). CLS is the constant laser source. The operations of the LM-NLM blocks are same as depicted in 'fig.-1'. Beam splitters, beam combiners and mirrors are not shown in the figure for simplicity.

Each of the input optical data signals 'A' and 'B' can be either 'logic 0' (i.e., polarized perpendicular to the plane of paper (●) and of a prefixed intensity 'I') or 'logic 1' (i.e., polarized in the plane of paper (↕) and of intensity 'I').

The light signal from input ‘A’ is divided into two parts each of intensity ‘I/2’ at the point ‘O_1’ with the help of a beam splitter. One part goes to polarizer ‘P_1’ while other part of the beam goes to polarizer ‘P_3’.

Similarly, the light signal from the input ‘B’ is divided into two parts each of intensity ‘I/2’ at the point ‘O_2’. One part goes to polarizer ‘P_2’ and other part of the beam goes to polarizer ‘P_4’.

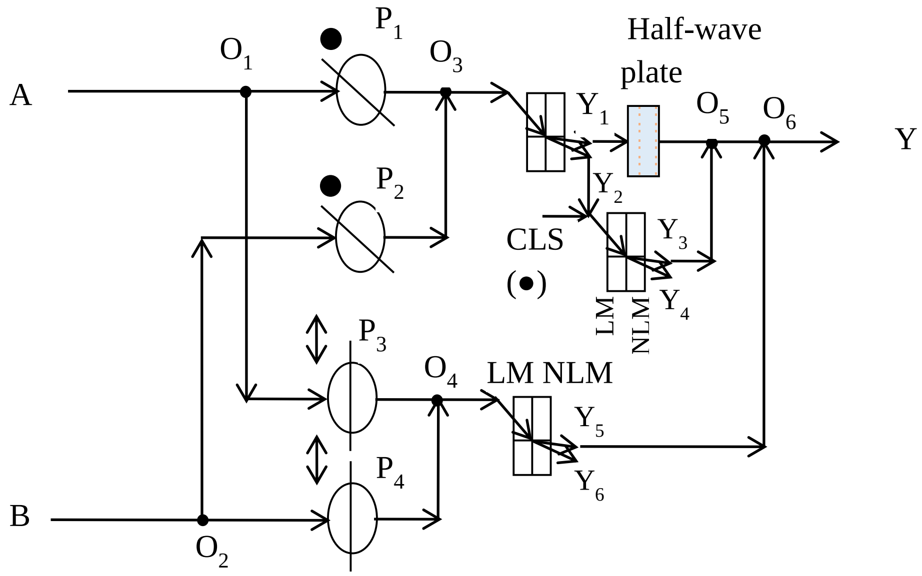

Fig.2: Polarization encoded optical XNOR logic gate

i) Now for first input condition, A=0, B=0; the light signal from input ‘A’ can pass through ‘P_1’ but cannot pass through ‘P_3’. Again, the light signal from input ‘B’ passes through ‘P_2’ but it cannot pass through polarizer ‘P_4’. At the point ‘O_3’, the two light signals (each of intensity ‘I/2’) from ‘P_1’ and ‘P_2’ are combined together. So, the combined beam intensity is ‘I’. This light signal is now passed through a LM-NLM block so that it is refracted to the channel ‘Y_1’ and no light signal is received in the channel ‘Y_2’. So, the light signal from the CLS (polarized perpendicular to the plane of paper (●) and of intensity ‘I/2’) is refracted through the second LM-NLM block towards the channel ‘Y_4’. No light is received in the channel ‘Y_3’. Now the light signal from the channel ‘Y_1’ is passed through a half-wave plate which transform the light beam from polarized perpendicular to the plane of paper (●) to a light beam polarized in the plane of paper (↕). This light beam is only present at the point ‘O_5’.

On the other hand, no light signal can pass through the polarizers ‘P_3’ and ‘P_4’. So, at the point ‘O_4’ no light signal is present. No light signal is received in the channels ‘Y_5’ and ‘Y_6’. Hence, at the point ‘O_6’ only the light signal from ‘O_5’ is present. At the output ‘Y’ a light signal polarized in the plane of paper (↕) (and of intensity ‘I’) is achieved.

Therefore, for input condition, A=B=0, output is Y=1.

ii) For second input condition A=0, B=1, the light signal from input ‘A’ passes through the polarizer ‘P_1’ but cannot pass through ‘P_3’. The light signal from input ‘B’ cannot pass through ‘P_2’ but can pass through ‘P_4’. So, at the point ‘O_3’ only the light signal (of intensity ‘I/2’) from ‘P_1’ is present. So, this beam is refracted through the nonlinear material to the channel ‘Y_2’ causing no light in the channel ‘Y_1’. The light signal from ‘Y_2’ is now combined with the light signal from CLS. The combined beam (of intensity ‘I’) is now refracted to the channel ‘Y_3’ resulting no light signal in ‘Y_4’.

On the other hand, at the point ‘O_4’ only the light signal coming from ‘P_4’ is present. This beam (of intensity ‘I/2’) after passing through the LM-NLM block travels to the channel ‘Y_6’. No light is received in the channel ‘Y_5’. So, at the point ‘O_6’ only the light signal from ‘Y_3’ is present. Hence, at the output ‘Y’ one receives a light signal polarized perpendicular to the plane of paper (●) (and of intensity ‘I’).

Therefore, for the input condition A=0, B=1, output is Y=0.

iii) For input condition A=1, B=0, light signal from input 'A' cannot pass through polarizer 'P_1' but can pass through 'P_3'. Light signal from input 'B' can pass through 'P_2' but cannot pass through 'P_4'. So, the situation is similar to the second input condition. At the point 'O_3' only the light signal from 'P_2' is present. So, this beam (of intensity 'I/2') is now travels to the channel 'Y_2' causing no light in 'Y_1'. The light signal from 'Y_2' is combined with the light signal from CLS. The combined beam (of intensity 'I') after passing through the LM-NLM goes to the channel 'Y_3'. No light is received in the channel 'Y_4'.

On the other hand, at the point 'O_4' only the light signal from 'P_3' is present. So, this beam (of intensity 'I/2') is refracted to the channel 'Y_6' causing no light signal in 'Y_5'. Hence, at the point 'O_6' only the light signal coming from 'Y_3' is present. So, at the output 'Y' a light signal polarized perpendicular to the plane of paper (●) (and of intensity 'I') is received.

Therefore, for the input condition A=1, B=0, output is Y=0

iv) For fourth input condition, A=1, B=1, input light signal from input 'A' cannot pass through the polarizer 'P_1' but it passes through 'P_3'. Input signal from input 'B' passes through 'P_4' but cannot pass through 'P_2'. So, at the point 'O_3' no light signal is present. As a result, no light signal is obtained in 'Y_1', 'Y_2' and 'Y_3'. The light signal from the CLS travels to the channel 'Y_4'. Thus, at the point 'O_5' no light signal is present.

On the other hand, due to the presence of light signal from 'P_3' and 'P_4' at the point 'O_4' the intensity of the combined beam becomes 'I'. So, this beam, after passing through the LM-NLM block, now travels to the channel 'Y_5'. At the point 'O_6' only the light signal from 'Y_5' is present. Hence, at the output Y a light signal polarized in the plane of paper (↕) (and of intensity 'I') is received.

Therefore, for the input condition A=1, B=1, output is Y=1

Thus, the truth table of XNOR logic gate is verified. So, the proposed scheme yields the output of a 2-input XNOR logic gate.

5. Conclusion

The proposed scheme utilizes both the polarization-based encoding and decoding technique and nonlinear material-based switching. The scheme is all-optical in nature. Real time operational speed can be achieved. As the intensity of the input and output light beams are same, the scheme can be connected with other optical systems conveniently. With the help of proper laser source, the proposed scheme can be used as a building block of an optical computer.

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