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Design of ternary Multiplexer and De-multiplexer circuit with optical nonlinear material (OPNLM) based switch

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ABSTRACT

Multiplexer and De-multiplexer operation play a very important role in all-optical computation, communication and control. Considerable number of multiplexing – de-multiplexing scheme in digital optical processing have already been reported. A design of all-optical ternary Multiplexer De-multiplexer circuit with optical nonlinear material (OPNLM) based switch is proposed and described in this paper. Different logic states have been represented by different polarization states of light. Logical simulation is also included here. This circuit will be useful in future all-optical multi-valued logic based computing and information processing system.

1. Introduction

The demand for high-performance computing needs improved circuit and device technology. Over the past few decades, scaling of device dimensions has proved to be an effective ploy in meeting the circuit performance requirements and in decreasing power consumption. Multi-valued logic (MVL) has a strong potential as a means to overcome the problems associated with the complexity of wiring and the amount of power dissipation in ULSI systems [1–8]. The success of the MVL approach, however, depends heavily on the availability of devices that are suitable for multi valued logical operations. Especially devices in which the operation of a multiple level quantization and a switching between them can easily be obtained are desired. All optical parallel computation uses the parallelism of optics with all its possibilities to overcome the limitations and restrictions for arithmetic and logical operations in optical domain. In high speed computation the suitability of using optics as information carrying signal is justified several times by many scientists and technologists [9–15]. It is not necessary to use only discrete gates (like AND, OR, NAND, NOR, EXOR, EXNOR) in the designing of the combinational logic circuit. With the availability of the medium scale integrated (MSI) and large scale integrated (LSI) systems, it is possible to design a very complicated circuit with a simple procedure, for example it is waste of time in most cases to try to minimize a combinational logic circuit which has eight inputs using tabular method, while it will be simpler if we use Multiplexer and De-multiplexer circuit. Multiplexing and de-multiplexing are two essential features in almost all the data and signal communication systems, where a lot of information is being handled without any mutual disturbances. Many scientists have proposed many ideas of designing the circuit of multiplex and de-multiplex logical operations in different ways [16–19]. Ternary and quaternary Multiplexer and De-multiplexer has been designed with terahertz optical asymmetric De-multiplexer (TOAD) based interferometric switch [20,21]. In this paper, we have designed a simple polarization encoded all-optical circuit to realize the ternary Multiplexer and De-multiplexer function with optical non-linear material (OPNLM) based switch. Polarization may be a good choice for representation of different logical states of all-optical multi valued logic operations because the strength or weakness of the beam does not play any role in polarization encoded logical operation, as the intensity of the beam does not carry any information. Also the state of polarization can be changed easily by using polarization converters [22,23]. In this paper, the polarization properties of light is used to represent different logical stares where

0 = horizontally polarized light (•),
1 = vertically polarized light (↕) and
2 = right circularly polarized light (◌).

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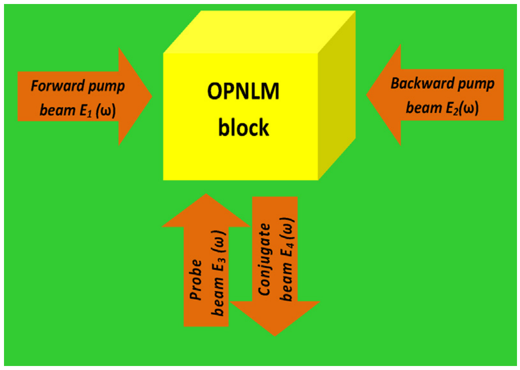

Fig. 1. Optical phase conjugation (OPC) operation of nonlinear material.

The paper is organized as follows. Section 2 gives the working principle of OPNLM based switch. Functions of components used to design ternary MUX-DMUX circuit are reported in Section 3. Section 4 presents the design and working principle of ternary MUX-DMUX circuit with OPNLM based switch. Results are given in Section 5. Paper ends with discussion and conclusion in Section 6.

2. Principle of working of OPNLM based switch

Optical phase conjugation is a mechanism of creating a beam from another beam with equal frequency, but in opposite phase. Mixing of four waves is mainly used to generate the phase conjugate wave. A forward and a backward propagating pump beams preferably laser, interact in an optical nonlinear material (OPNLM), which has at least a cubic type of nonlinearity. When the third probe beam is introduced at an angle, a reflected conjugate beam is generated (shown in Fig. 1) [24].

The total field of the nonlinear medium is [25]

$$E(t)\infty\frac{1}{2}[E_f+E_b+E_p+\text{complex}\quad\text{conjugate}]^3$$

where E_f, E_b and E_p are the electric field vectors of the forward, backward and the probe beam respectively. It is interesting to note that the output beam will not emerge if any one of the pump beam is absent or both the beams are absent. This optical switch will operate only if its two input beams are coherent in nature and then only the real time gratings in the optical materials are formed. The organization of entire switching operation needs the support of phase matching condition between the pump and the probe beams. The pump beams have the high power while the probe is weak. The energy of the pump beams is transferred to the conjugate probe beam as a multiplicative gain term. When two pump beams are made collinear, the reflected beam exactly retraces the path of the probe beam.

The proposed all-optical scheme can exhibit its switching speed far above than the present day electronic switches. The switching mechanism of the OPNLM block depending on different polarization state of the pump beams and the probe beam is given in Table 1 along with a diagram given in Fig. 2. Here the switching mechanism is explained for a specific pair of polarized lights (HPL and VPL), but the mechanism is same for any pair of polarized lights.

3. Design of all optical ternary Multiplexer and De-multiplexer circuit

The operation of ternary Multiplexer and De-multiplexer depends on the function of a polarization isolator block (PI-block), two composite blocks (CB-1 and CB-2) and an OPNLM matrix (acts as an optical switch). The working mode of all these blocks is given below in details.

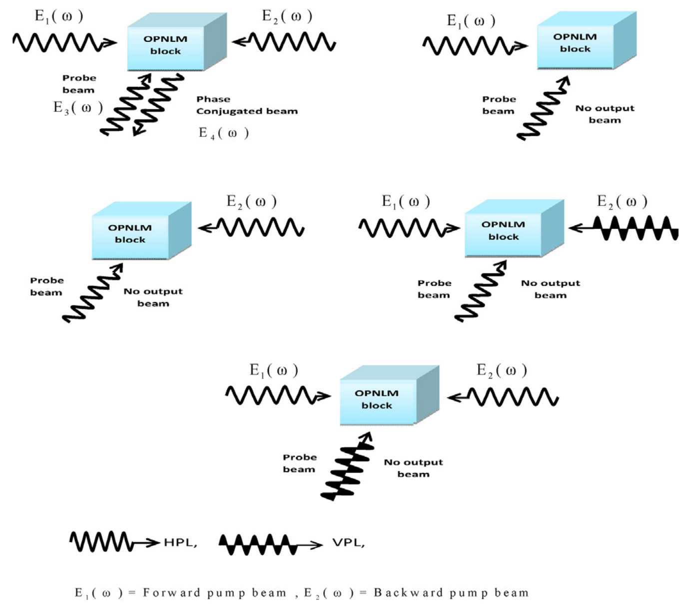

Fig. 2. Switching mechanism of OPNLM block.

3.1. Polarization isolator block (PI-block)

A polarization isolator isolates (i.e. passes) a particular type of polarized light and blocks the other types. In our proposed circuit we have used a polarization isolator block which is a (3 × 3) matrix, shown in Fig. 3.

The first row (A_{11}, A_{12} and A_{13} pixels) contains horizontally polarization isolator (HPI), which isolates the horizontally polarized light (HPL) only and blocks the VPL and RCPL respectively.

The second row (A_{21}, A_{22} and A_{23} pixels) contains vertically polarization isolator (VPI), which isolates the vertically polarized light (VPL) only and blocks the other types.

The third row (A_{31}, A_{32} and A_{33} pixels) contains right circularly polarization isolator (RCPI), which isolates the right circularly polarized light (RCPL) only and blocks the other types.

3.2. Composite block-1 (CB-1)

The composite block-1 is made of two layers (shown in Fig. 4). The first layer of the side view is the polarization isolator matrix (PI_1-matrix) and the second layer is the polarization converter matrix (PC_1-matrix) of the composite block-1. Both the matrices are of (3 × 3) rank. Here PI_1 matrix contains only one type of polarization isolator, HPI. So when the light from the source incidents on PI $_1$ block, then the light coming out from all the pixels of the PI_1 block will be horizontally polarized light. The PC_1 matrix contains different types of polarization converters, which converts one type of polarized light into another type. The function of all these converters can be explained with the help of mathematical analysis of Jones matrix [26,27].

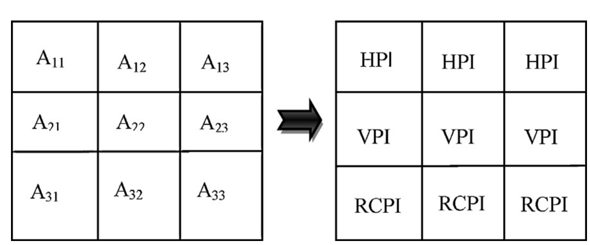

Fig. 3. Polarization isolator (PI) block.