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All-optical Serial Data Transfer between Registers using optical non-linear materials

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ABSTRACT

The inherent parallelism of optical signal is an advantageous feature for high-speed computations and other digital logic operations. Different techniques have been proposed for performing arithmetic, algebraic and logic operations using light as the information-carrier. Here we propose a new method for Serial Data Transfer between Registers using optical non-linear material. This system is all-optical in nature. Optical NAND gate and NOT gate are the basic building blocks of this system.

1. Introduction

In the last few decades it has been established that there is no other alternative of optics in case of high speed computation. Even an operation of terahertz speed can be achieved when photon is used as an information-carrier. To use photon as information-carrier one should use optical switch, where non-linear materials play important role [1].

Scientists and technologists are trying to construct a hybrid structure where the conventional electronic Arithmetic Logical Unit will be replaced by an optical parallel processor. Here binary data '1' is expressed as the presence of light and '0' is considered as the absence of light. In achieving this goal there are several established techniques for conducting all-optical arithmetic, algebraic and logic operations [2–8].

In the present communication we introduce a new concept of Serial Data Transfer between Registers. We show that such transfer is possible using optical non-linear material based optical NAND and NOT gates which are the basic building blocks of this system.

2. Optical non-linear material (N.L.M.) as optical switch

It is known that there occurs no change in the Refractive Index (R.I.) of a linear material if light (polarized laser radiation) of any intensity is incident upon it. However, for some non-linear materials Refractive Index (R.I.) changes according to the intensity of incident light [9,10]. The equation of change in R.I. of the non-linear material related with the intensity of incident light is

$$n_{\mathrm{NL}} = n_0 + n_2 I_1 \quad (1)$$

where n_{NL} is the refractive index (R.I.) of non-linear material (N.L.M.), n_0 is constant R.I. term of N.L.M. n_2 is 2nd order non-linear correction term. I_1 is intensity of incident light that penetrates through the non-linear material.

Carbondisulphide (CS_2), pure silica glass, GaAs, etc. are the example of such type of non-linear materials. In case of CS_2, the value of n_0 is 1.62 and n_2 is $0.22 \times 10^{-19}\,\mathrm{m^2/W}$. When it is used as non-linear material it can focus a laser beam of cross-section 1 cm radius and 10 MW power at a distance of 10 cm. This character of a material is known as self-focusing character. Not only carbondisulphide, all the materials which have the self-focusing character can be used easily for all-optical switching operations. The focusing length (L) of non-linear material depends on the power (P) and the area of cross-section (a) of the laser beam with the relation

$$P = \frac{\pi \varepsilon_0 n_0 C a^4}{8 n_2 L^2}$$

where ε_0 and C are the free space permittivity and free space velocity of light. From the above equation it is clear that the focusing length (L) will be shorter with the increase of the power of the beam and with the optimum decrease of the radius of the beam. In the integrated optical system all the components (switches) are in sub-micron-level dimension. So, to implement an integrated opti-

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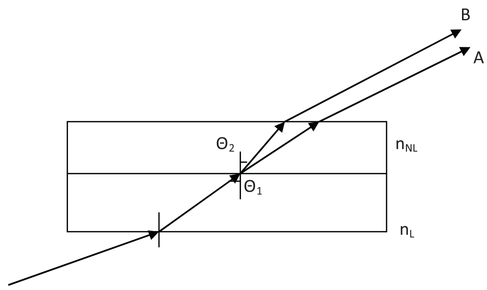

Fig. 1. Optical N.L.M. as optical switch.

cal system with this type of non-linear material we require a very high power laser with a diffraction limited standard beam size.

An optical switch can be prepared using this intensity-based R.I. property of non-linear material. For this we make a combination of linear and non-linear media, where n_L and n_{NL} are the R.I. of linear and non-linear materials respectively.

Suppose, a beam of polarized laser light of intensity I_1 is incident upon the linear medium (Fig. 1) in a certain angle and passes through the non-linear medium to give an emergent ray in direction 'A'. Now, if the intensity of incident light increases then the light ray goes to direction 'B'. From Eq. (1), it is seen that n_{NL} is increased when I_1 is increased. Also, as n_{NL} is increased, obeying Snell's law θ_2 is decreased and incident light of higher intensity passes through the N.L.M. following direction (B).

In this switching scheme, CS_2 or pure silica glass may be used as an optical non-linear material. Nd:YAG laser with 1.064 μm wave length is an ideal source to activate the non-linear material in the switching operation.

Now we discuss about the change of output refraction angle from the non-linear material due to the change of input intensity level. If pure fused silica is used as non-linear material, the n_0 and n_2 for it are 1.46 and 3.2×10^{-20} m^2/W respectively. When an ordinary laser of power 100 mW and cross-section 50 μm^2 is taken, we can get its intensity of about 2×10^9 W/m^2. This produces a change in the refractive index ($\Delta n = n - n_0$) of the non-linear material which is 64×10^{-12}. Apparently this change is irrelevant. But the situation will be changed if we use pulse laser instead of a continuous laser beam. An ordinary Q-switched pulse laser having 10^{-7} s on-time duration for each pulse can be used as input signal. For pure fused silica if the above laser (100 mW continuous power) is used for getting 10^{-7} s on-time duration pulse laser, we can achieve $\Delta\theta$ (the angular change of the direction of the output light from non-linear material after refraction) as 0.013° or 0.24×10^{-3} rad, when the intensity is increased twice keeping the input incident angle fixed at 45°.

The value of $\Delta\theta$ will be 1.20°, when 10^{-9} s on-time duration pulses are used from 100 mW continuous laser keeping other requirements constant. For CS_2, $n_2 = 0.22 \times 10^{-19}$ m^2/W, so the value of $\Delta\theta$ is higher than that of silica.

3. Optical NAND and NOT logic gate by optical N.L.M.

3.1. Optical NAND gate

For an optical NAND gate we make a composite slab of linear and non-linear material as shown in Fig. 2. There A, B are input beams of same intensity '*I*'. C.L. is a constant light source of intensity '*I*'.

When intensity of incident light is *I* then rays of light go along the path A_1. When intensity of incident light is $2I$ $(I+I)$ then it goes along the path B_1. When intensity of incident light is $3I$ $(I+I+I)$ then it goes along the path C_1. With the help of convex lens (L), out put Y is taken with the combination of paths (A_1) and (B_1).

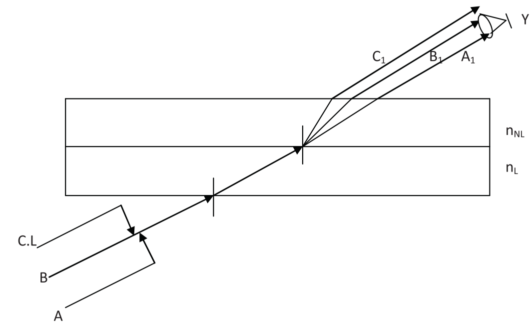

Fig. 2. Optical NAND gate.

Table 1
Truth table of optical NAND gate.

Input		Output
A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

Switching operation for NAND gate:

(i) When $A = B = 0$, then only for C.L. the intensity of incident light ray is *I* and goes through N.L.M. along with path (A_1), at this stage output $Y = 1$.
(ii) When $A = B = 1$, then intensity of incident light ray is *I* for *A*, *I* for *B* and *I* for C.L. in total 3*I*. So ray of light goes through N.L.M. along with path (C_1), at this stage output $Y = 0$.
(iii) When $A = 0$, $B = 1$, then the intensity of incident ray is 0 for *A*, *I* for *B* and *I* for C.L., in total 2*I*. Then the ray of light passes through N.L.M. along with path (B_1). Then output of the optical NAND gate $Y = 1$.
(iv) When $A = 1$, $B = 0$ then intensity of incident ray is in total 2*I*. Then the output $Y = 1$.

The truth table of optical NAND gate is given in Table 1.

If necessary, the output intensity level can be maintained at the desired intensity level (*I*) by proper mechanism [11].

A lens of cross-section 200 μm^2 can be used for combining the path of ray of intensity '*I*' and '2*I*' (path A_1 and B_1).

3.2. Optical NOT gate

To develop an optical NOT gate, we make the composite slab of linear and non-linear material (Fig. 3), where *A* is the only input path and C.L. is the constant light source having intensity '*I*'.

To select the output of optical NOT gate the path of intensity '*I*' (A′) is taken.

Switching operation for NOT gate:

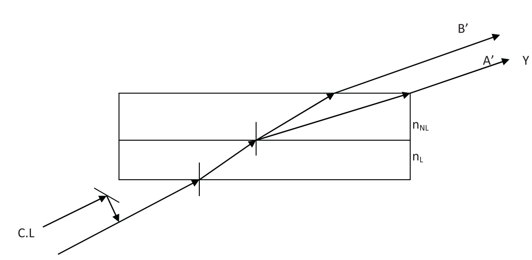

Fig. 3. Optical NOT gate.