

Implementation of 1-Bit Random Access Memory Cell in All-Optical Domain with Non-linear Material

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Abstract This paper demonstrates an all-optical 1-bit Random Access Memory (RAM) with massive use of nonlinear material. All-optical switching mechanism is exploiting here to realize the all-optical 1-bit RAM. The all-optical switch by a composite slab of linear medium (LM) and non-linear medium (NLM) is the building block of our proposed 1-bit RAM circuit. An all-optical clocked D flip flop is the main storing element of the RAM. These circuits are simple and all-optical in nature. It can also gear up to the highest capability of optical performance in high-speed all-optical data storing, computing and communicating system.

Keywords Nonlinear Material, All-Optical Switch, All-Optical D Flip-Flop, 1-Bit Read/Write Memory Cell, All-Optical RAM

1. Introduction

To cope with the explosive growth of the internet traffic, the expected necessity for parallel, ultrahigh speed, ultrahigh bandwidth, no crosstalk, low loss information processing[1] has provided remarkable impetus for understanding of all-optical devices and circuits[1-3]. Last few years have witnessed an enhanced weight in optical communication[3-4] and computing[5] due to some important advancement, namely, the development of laser, optical fiber and novel materials that exhibit high nonlinearities[1, 5-12]. These developments of optics offer tremendous scope to overcome the obstacle to implement various arithmetic[2, 7-8], logic[9-14, 18-20], algebraic[15] and image operations[16] in all-optical domain successfully. The advent of non-linear optical material based all-optical switching mechanism[1, 5-12, 18, 25] has opened exciting new possibilities for improvement of several new all-optical components of terahertz all-optical computer, our dream goal.

This promising technique of all-optical switching can show its potential in combinational logic circuits[2, 7-8, 17] as well as sequential logic circuits[9-12, 18]. For examples, all-optical S-R, S-R with clock, D, J-K and J-K master-slave type flip-flops using non-linear material[9-12, 18-20], all optical register[11, 22-23], all optical counter[12] have been reported. Various all-optical memories have also been proposed[22-24]. They are not as fast as to fulfil the demand of

now-a-days. To gear up the performance speeds (storing speed and retrieving speed) we implement an all-optical 1-bit random access memory[21] which is constructed by the clocked D flip flop[9,11]. This circuit can raise to a higher bit other types of RAM. As this 1-bit RAM is purely all-optical in nature, it is very simple as well as very fast. Also the scheme has capacity of cascading. These circuits are key elements for the implementation of a high-speed, all-optical data processing device, which has the potential to outperform its electronic equivalent and constitute a possible new product for next generation computation[1,5] and communication[3-4] to scale their capacity to the traffic demand.

2. Ultra Fast All-optical Switching behaviour of Nonlinear Material and their Application in All-Optical NOT Gate as well as AND Gate

The phenomenon photorefractivity[6, 8-12] of some nonlinear optical material is used in nonlinear all-optical intensity switching mechanism. The refractive index[1, 6, 8-12, 25-27] of some nonlinear materials (NLM) such as carbon disulfide, pure silica, potassium dihydrophosphate (KH₂PO₄), (KDP) crystal etc. varies linearly with the intensity of the light incident on it. The refractive index (n) of such isotropic dielectric non-crystalline media can be put into an equation as in (1). Here n_0 is the linear term, n_1 is the nonlinear correction term and I is the intensity of the incident light beam on the material.

$$n = n_0 + n_1 I \quad (1)$$

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2.1. Ultra Fast All-Optical Switching Behavior of Nonlinear Material

We can implement the switching mechanism with such nonlinear material by taking an interface between two media of which one is a linear material (LM), whose refractive index n_0 is independent of the intensity of light and the other is aforesaid NLM. A laser beam, highly intense polarized light, preferably pulse laser of intensity I_1 , is allowed to incident on the interface from linear to nonlinear part in a particular direction XO (incidence angle θ_1) as depicted in Figure 1. The refracted beam from the NLM follows the path OZ. But when another higher intense laser beam of intensity I_2 ($I_2 > I_1$) is made to incident along XO, after refraction from the NLM the light passes through OY direction (angle of refraction θ_2). The deviation of refractive angle for different incident light intensity I_1 and I_2 is $\angle ZOY = \Delta\theta_2$. Thus the combination of LM and NLM may act nicely as a directional all-optical switch. This is the unit block of our proposed 1-bit random access memory cell.

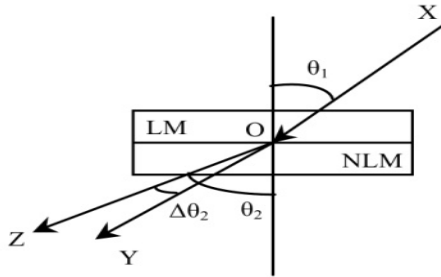


Figure 1. Intensity switching of optical nonlinear material

In the expression of refractive index in (1) n_0 is linear term and n_1 is the nonlinear correction term. For carbon disulfide [8, 10-12, 25] (CS_2) $n_0 = 1.63$, $n_1 = 514 \times 10^{-20} \text{ m}^2/\text{W}$. and for fused silicon dioxide [8, 10-12, 25] (SiO_2) $n_0 = 1.458$, $n_1 = 2.7 \times 10^{-20} \text{ m}^2/\text{W}$. If we use CS_2 and SiO_2 as nonlinear materials and the pulse laser of intensity $I = 2 \times 10^{18} \text{ W/m}^2$ as a source, we can estimate the deviations of light in two cases as given in Table 1.

The logic gates [7-12, 18] are implemented in optics using NLM by taking the presence of light signal as 1 and the absence of it as 0. The implementation of such logic gates can be done by using some femtosecond laser pulses and 1-mm-thick KDP crystal at the peak intensity of 0.6 TW/cm^2 and duration of 60 fs [8, 10-12, 26]. M. Choi et al. show that a single-layer terahertz metamaterial [27] has a peak refractive index of 38.6 while maintaining low losses. It is a broadband, extremely high index of refraction going beyond the limit that is attainable with naturally existing substances, lead sulphide, strontium titanate [27].

2.2. All Optical NOT Gate

To implement an all optical NOT gate using non-linear material a constant intensity pulse laser source (CILS) is used as shown in Figure 2. It is also called probe beam. Here P_1 is taken as input beam. A detector is placed at P_2 will detect the output beam after refraction. If P_1 is absent, the

light will follow a path OP_2 and will be detected by the detector due to presence of CILS. But if P_1 is present, after refraction, the light will follow a path other than OP_2 , may be OP_3 , and the detector will not detect any light signal. Thus the system acts as optical NOT gate.

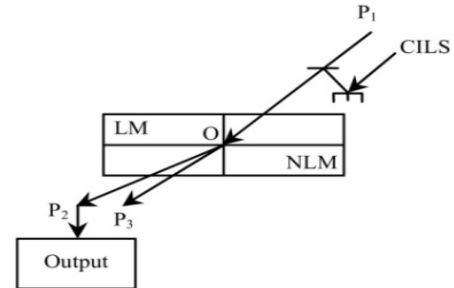
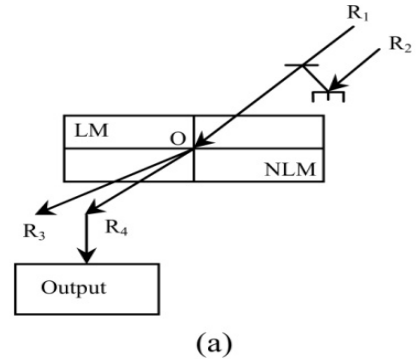


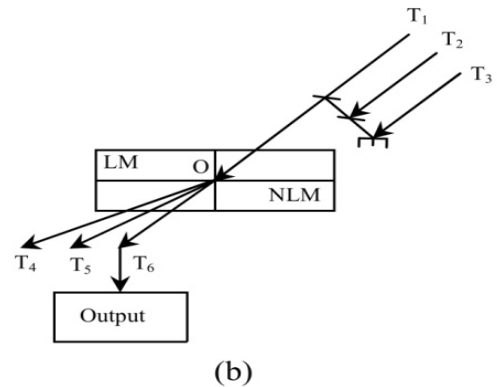
Figure 2. All-optical NOT gate

2.3. All Optical AND Gate

The all-optical AND gate using two inputs and three inputs are shown in Figure 3. The two inputs all-optical AND gate using NLM is shown in Figure 3(a). Here R_1 and R_2 are two input channels. A detector placed at R_4 gives the output. Now when both the channels carry light signal, the light beam after refraction will be detected by the detector at R_4 , unless not.



(a)



(b)

Figure 3. All-optical AND gate using NLM. (a) two-input AND gate. (b) three-input AND gate

The three inputs all-optical AND gate using NLM is shown in Figure 3(b). Here T_1 , T_2 and T_3 are three input channels. A detector placed at T_6 gives the output. Now when all the channels carry light signal, the light beam after refraction will be detected by the detector at T_6 , unless not.

Table 1. Estimation of the Deviation of Pulsed Laser Light when Passing Through Carbon Disulfide (CS₂) and Silicon Dioxide (SiO₂)

Material	Angle of Incidence (θ_1)	Incident light intensity	n ($= n_0 + n_1 I$)	Angle of refraction (θ_2)	Deviation ($\Delta\theta_2 = \theta'_2 - \theta''_2$)
carbon disulfide (CS ₂)	45 deg	$I=2 \times 10^{18}$ W/m ²	11.91	3.404 deg = θ'_2	1.578 deg
	45 deg	2I	22.19	1.827 deg = θ''_2	
silicon di-oxide (SiO ₂)	45 deg	$I=2 \times 10^{18}$ W/m ²	1.512	27.883 deg = θ'_2	1.041 deg
	45 deg	2I	1.566	27.842 deg = θ''_2	

3. All-optical 1-bit Random Access Memory Cell

We now describe the all-optical circuit of 1-bit random access memory (RAM) cell as shown in Figure 4. Here D_i is the Data Input of the 1-bit RAM and D_0 is the Data Output of the cell. There are two other inputs namely Address Select input (A_n) and Read/Write Control input (R/\bar{W}). The main storing component of this RAM cell is the clocked D flip-flop[9, 11] shown in the dash box as in Figure 4. The truth table is depicted in Table 2. Except the D flip-flop, here we use one all-optical NOT gate (NG6) and two AND gates (AG5 and AG6). AG5 is a two-input AND gate while AG6 is a three-input AND gate. All the gates are based on optical nonlinear material as the basic building block of our proposed RAM cell. The R/\bar{W} input is complemented at the D_{10} terminal through NG6 due to the presence of probe beam CILS6. Now AG5 has A_n and D_{10} as two inputs and E_{11} as output. Again Data Input (D_i) of the RAM cell is fed to D input of the D flip-flop and E_{11} is fed as clock (CLK) of the D flip-flop. The flip-flop has outputs Q and \bar{Q} , complement to each other. A_n , R/\bar{W} and Q are the three inputs of the AND gate AG6. The output (F_{12}) of AG6 is the final output (D_0) of the proposed all-optical 1-bit Read/Write memory cell.

Table 2. Truth Table of Clocked D Flip-Flop

Inputs		Outputs	
CLK	D	Q_{n+1}	\bar{Q}_{n+1}
0	d	Q_n	\bar{Q}_n
1	0	0	1
1	1	1	0

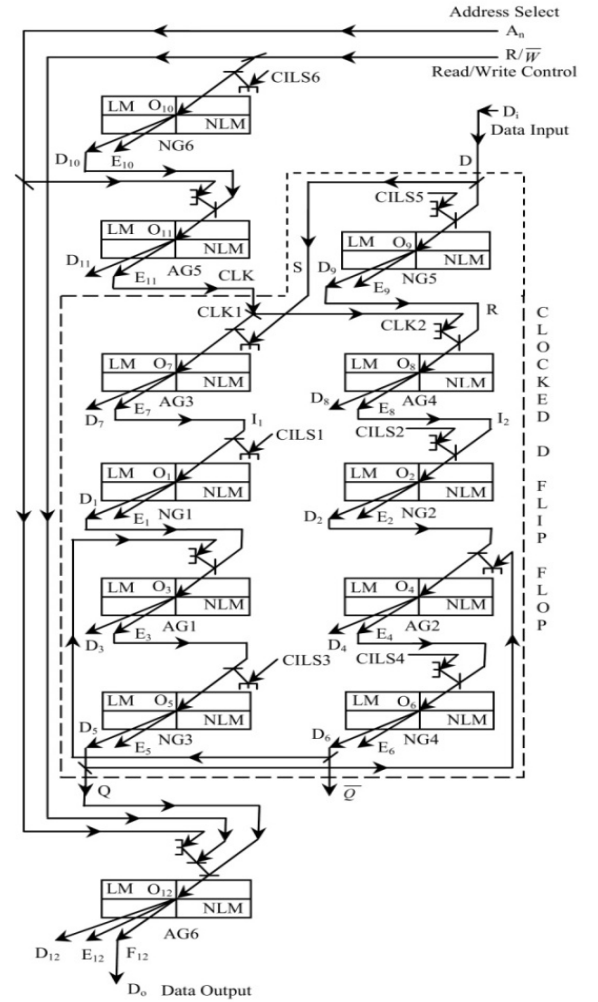
d = whatever may be the input

Let us discuss the operation of the circuit to form the function table of the 1-bit RAM cell.

(1) First we take $A_n = 0$, i.e. A_n carries no light signal. As AG5 and AG6 are AND gates, E_{11} ($= \text{CLK} = 0$) and F_{12} ($= D_0 = 0$) remain dark irrespective of the inputs R/\bar{W} and D_i . Now CLK of the D flip-flop is absent which preserved the previous state ($Q_{n+1} = Q_n$). So as long as $A_n = 0$, the input and output activities are blocked, and the cell is in the hold mode where its stored data is protected.

(2) If Address Select input bears photon ($A_n = 1$), the cell is enabled for writing and reading operation. There are two

possibilities.

**Figure 4.** All optical random-access memory cell using NLM as switch

i) The first possibility, R/\bar{W} is equal to 0. Then the output D_0 ($= F_{12}$, output of AG6) becomes 0 independent of Q. i.e. the output of the cell is detached from Q. One cannot read from the memory cell in this state. But light will follow the path $O_{11}E_{11}$ when passing through AG5 as both the input beams ($A_n = D_{10} = 1$) have light. Now the clock of the D flip-flop becomes at logical '1' state. So the D flip-flop stores 0 if $D_i = D = 0$ and writes 1 if $D_i = D = 1$ according to Table 2. Therefore, if $A_n = 1$ and $R/\bar{W} = 0$, writing (storing) operation of single bit data (D_i) is done into the memory cell.

Table 3. Function Table of All-Optical 1-Bit Read/Write Memory Cell

Inputs			Outputs			Mode
A_n	R/\overline{W}	$D_i = D$	CLK	Q_{n+1}	D_0	
0	d	d	0	Q_n	0	Hold
1	0	0	1	0	0	Write 0 into memory
1	1	d	0	0	0	Read, D_0 = stored D_i bit
1	0	1	1	1	0	Write 1 into memory
1	1	d	0	1	1	Read, D_0 = stored D_i bit

d = whatever may be the input

ii) In the last possibility we consider R/\overline{W} as 1. There will be no light at E_{11} terminal as $D_{10} = 0$. Again the clock of the D flip-flop is absent. The flip-flop remain in its former output state ignoring D (= D_i) input. In the present situation none can write into the memory cell. But for AG6, as two inputs ($A_n = R/\overline{W} = 1$) are at logically high state, the output follows the third input Q. That means Q comes out at D_0 through $O_{12}F_{12}$ direction. Q is nothing but the stored D_i bit. So we can conclude that stored digital data will be retrieved from 1-bit read/write memory cell when both the inputs A_n and R/\overline{W} transmit light.

The function table is given in Table 3. All-optical 1-bit RAM cell can store digital optical data and retrieve it as desired. In our scheme we use all optical AND and NOT gate in designing the all optical 1-bit RAM cell. In our design the light beam which is fed back is coming from the output of a NOT gate. Again the concept used here to design the all optical NOT gate has an advantage. Whenever the output of a NOT gate is assumed to be at '1' state, the source of that '1' state is a constant intensity pulse laser source (CILS) used as probe beam. So in each feedback arrangement described in our scheme similar intense light beam is fed back. In this way the reduction of intensity by using beam splitter will not affect the non-linear response of the device. The light sources are so chosen that each input beam intensity is in the range of intensity which is detected as '1' by the detector after refraction. The source of the final output (D_0) of the RAM cell is CILS3. As long as the power is on, the stored data bit is protected and the data retrieval is possible. Therefore the proposed all-optical RAM cell can be used as volatile memory cell.

5. Conclusions

The proposed technique of all optical implementation of all optical 1-bit RAM cell is very fast (above THz)[8-12, 26-27] as it is fully all-optical. It is volatile in nature. The storing and reading time of this memory cell will be in fs. The light signals which are severally used and the feedback light signals from the outputs are made by mirrors and beam splitters to make the circuits simple. Another important feature is that other higher order all-optical temporary data storage memories may be developed by cascading the cell.

Other different types of memories can be implemented from this read/write memory cell. Proper findings of non-linear material[25-27] may be a significant issue here. Essentially inputs and constant intensity light source should be chosen properly to run the system accurately. The clock pulse signal should also be selected suitably.

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