Designing of an all-optical time division multiplexing scheme with the help of nonlinear material based tree-net architecture

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In the field of optical interconnecting network and in super fast photonic computing system, the tree architecture and optical nonlinear materials can play a significant role. Nonlinear optical material may find important uses in optical switching. Optical switch using nonlinear material makes it possible for one optical signal to control and switch another optical signal through nonlinear interaction in a material. In this communication such materials have been successfully exploited to design an all-optical tree-net architecture, which can be utilized for time division multiplexing scheme in all-optical domain.

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Multiplexing and demultiplexing are two essential features in almost all the data and signal communication and networking systems, where a lot of information is being handled without any mutual disturbances. Electronic systems are incapable of processing a large number of data at high speed (far above gigahertz). Optics is a promising candidate in this regard[1−6]. Here the traditional carrier of information, electron, is envisaged to be replaced by photon for devices based on switching and logic. In this case, terahertz (THz) range of operational speed can be achieved. The dream of photonics is to have a completely all-optical technology. Optical nonlinear material (ONLM) provides a major support to optical switching based all-optical logic and algebraic processing[7−10]. In the field of optical interconnecting network system, the tree-net architecture also takes an important role[11,12]. In this communication we have tried to exploit the advantages of special character of ONLM and the inherent advantages of optical tree-net architecture simultaneously for designing a time division multiplexing scheme which will work in all-optical domain. The proposed all-optical multiplexer can exhibit its switching speed far above present day electronic switches.

Optical switch, using a nonlinear material, makes it possible to change the direction of outgoing beam (optical signal)[7−10]. Recent researches show that polydiacctylenes (a highly conjugated polymer with very large optical nonlinearities) can show very fast response time (picoseconds response). This response time is hundred times faster than the fastest electronic switching. These nonlinear materials are exposed to high intensity laser beam. An Nd:YAG laser with 1.064-μm wavelength is ideal source to excite the nonlinear materials for switching operation. The refractive index of some kind of nonlinear materials can be expressed as

$$n = n_0 + n_2 I, \tag{1}$$

where n_0 is a constant term, n_2 is coefficient of nonlinear correction term, and I is the intensity of input light beam. Pure silica (SiO_2) glass and carbon disulphide (CS_2) can also show this type of optical nonlinear feature. Especially for CS_2, the value of n_0 is 1.62 and n_2 is 0.22×10^{-19} m^2/W^2. A laser having the cross section of 1-cm radius and 10-MW power can be focused at a distance of 10 cm if CS_2 is taken as nonlinear material. Equation (1) shows that refractive index of nonlinear material increases with the increase in intensity of the light beam. Hence, the direction of output light is changed with the change of intensity of input beam. This phenomenon is shown in Fig. 1. Here the system is made up of a combination of linear material (LM) and nonlinear material (NLM)[7,9]. When both the inputs (input beam-1 and input beam-2) are present, the output light follows OZ_1 direction i.e. upper channel. As in this case, presence of two signals increases the intensity of light beam and hence refractive index according to the above mentioned equation. But when only one input is present (either input beam-1 or input beam-2) the light intensity is less. As the intensity is less, the refractive index is less. Hence outgoing beam moves through lower channel, i.e. in OZ_2 direction. In our present proposal, the above

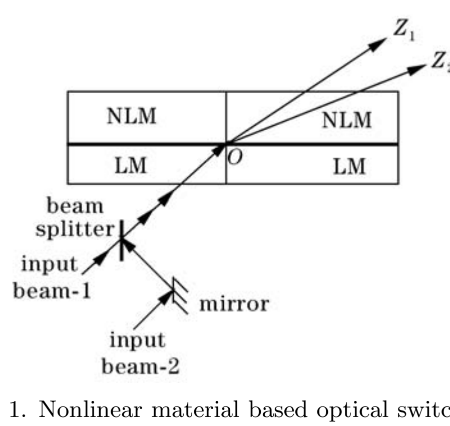

Fig. 1. Nonlinear material based optical switching.

characteristics of NLM is utilized for designing a tree-net architecture in all-optical domain which can successfully be exploited for time division all-optical data multiplexing scheme.

Tree architecture is a multiplying system of single straight path into several distributed branches and sub-branch paths[11,12]. This structure is explained in Fig. 2. Here a light beam MN emitting from a point M breaks into two parts NO and NP. These two beams break again into four parts, i.e. NO to OQ, OR and NP to PS, PT. Proceeding in this way more output channels could be obtained from a single input light beam. If the situation requires more spatially distributed output channels or terminals, another splitting arrangement is to be inserted in the last output channels.

NLM based switching system, discussed above, can successfully be used for implementation of optical tree architecture (OTA) as shown in Fig. 3. The light from constant light source, which is a laser source, is incident on switch s_1 first. Three NLM based optical switches s_1, s_2 and s_3 are to be kept at N, O and P respectively. The operational principle of these switches has already been discussed. These switches control the light in such a manner that, in the absence of control signal (which is also a light beam having the same prefixed light intensity), the incident beam coming from constant light source (CLS) emerges through lower channel. The presence of control signal changes the light intensity and hence refractive index of the medium. Therefore, the light signal is switched over to upper channel. Light coming from constant light source is incident on switch s_1 first. The control signal is considered to be as one (1) state when light beam is presented with prefixed intensity and zero (0) when light beam is absent. For two control signals A and B there are four possible combinations 00, 01, 10, 11. Let us explain the implementation of optical tree using NLM based optical switches as shown in Fig. 3 in detail.

Case 1: when $A = 0$ and $B = 0$. The light which comes from CLS is incident on switch s_1 first. As here $A = 0$, the control signal A is absent. That means only one light beam is present at s_1. According to the switching principle, discussed above, the light from CLS emerges through lower channel and falls on switch s_3 at P. Here the control signal B is also absent. That means here also only one light beam is present at s_3. Hence, the light finally comes out through lower channel of s_3 and reaches at terminal-1 (T-1). In this case, no light is present at other terminals terminal-2 (T-2), terminal-3 (T-3) and terminal-4 (T-4). So T-1 is in one state and others are in zero state, when $A = B = 0$.

Case 2: when $A = 0$ and $B = 1$. Light from constant light source is incident on s_1. As $A = 0$, light beam emerges through lower channel and falls on s_3. At s_3, the control signal B is present. That means two light beams are present. Presence of two beams increases the intensity of light and hence refractive index. Therefore, the light emerges through upper channel of s_3 and finally reaches at T-2. In this case light is only present in T-2. Hence T-2 is one state and others are zero, when $A = 0$ and $B = 1$.

Case 3: when $A = 1$ and $B = 0$. The light from CLS is incident on switch s_1 first. As here $A = 1$, the control signal A is present. That means two light beams are present at s_1. As a result of that the light emerges through upper channel of s_1 and falls on s_2 at O. As $B = 0$, no control signal is present at B that means only one light beam is present at s_2. Hence, the light comes out along lower channel of s_2 to reach at T-3. So the T-3 is in one state and others are in zero, when $A = 1$ and $B = 0$.

Case 4: when $A = 1$ and $B = 1$. The light from CLS is incident on switch s_1 first. As here $A = 1$, the input control signal A is present. That means two light beams are present at s_1. Because of that, the light emerges through upper channel of s_1 and falls on s_2 at O. As $B = 1$, the control signal is present at B that means two light beams are present at s_2. Hence, the light follows the upper channel of s_2 to reach at T-4. So the T-4 is in one state and others are in zero, when $A = 1$ and $B = 1$.

Multiplexing means many into one. A multiplexer is system dealing with many inputs and only with single output. By applying proper control signal, we can steer the input data signal to one of the required output channels. In our proposed multiplexing scheme, D_0, D_1, D_2, and D_3 are the input data signals, A and B are the control signals and Y is the output signal. Block diagram of a multiplexer (4 × 1) is shown in Fig. 4.

Switching character of nonlinear material, discussed above, can be exploited successfully for designing an all-

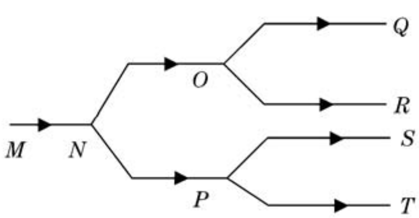

Fig. 2. Optical tree architecture.

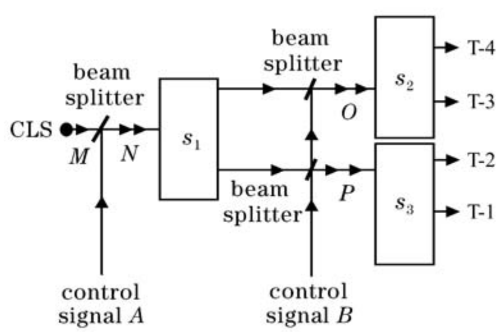

Fig. 3. Optical tree architecture with NLM based optical switch.

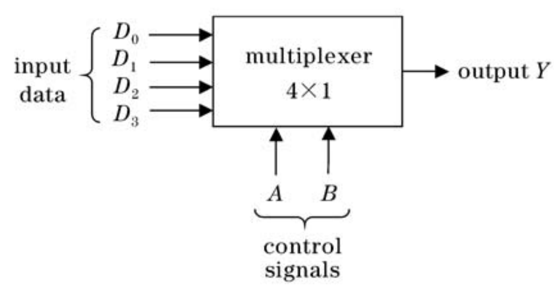

Fig. 4. Block diagram of a (4 × 1) multiplexer.

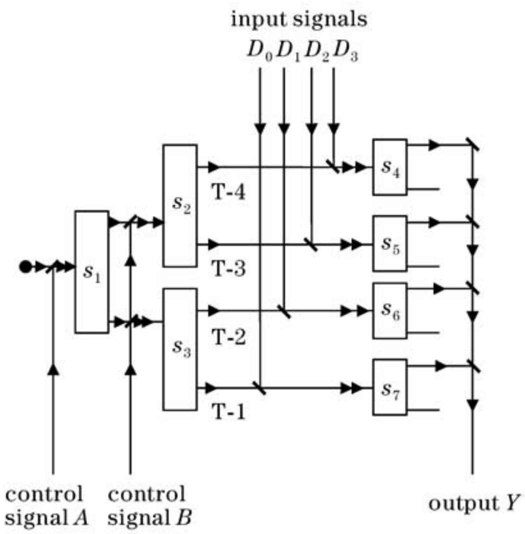

Fig. 5. All-optical multiplexing scheme (4×1).

optical multiplexing scheme. Here, NLM based tree-net architecture plays the role of control unit. Figure 5 shows the exploitation of tree-net architecture for designing all optical multiplexing schemes (4×1). In this figure, the switches s_1, s_2 and s_3 are used to implement optical tree architecture that is a control unit. A and B are the control signals in that control unit. The outputs of s_2 are fed to s_4 and s_5 (T-4 is connected to s_4 and T-3 is connected to s_5) whereas the outputs of s_3 are fed to s_6 and s_7 (T-2 is connected to s_6 and T-1 is connected to s_7). D_0, D_1, D_2 and D_3 are four input data signals (which are also the light beams) and are supposed to be connected with s_7, s_6, s_5 and s_4 respectively. Light emerging out from upper terminals of s_7, s_6, s_5 and s_4 only is combined to form the final output Y. In our circuitry design, the output from the lower channel of s_7, s_6, s_5 and s_4 is not taken.

First case: let us consider, $A = 0$ and $B = 0$ (i.e. no light signal is supplied to A and B). In this case light from CLS reaches only to s_7 through T-1. Now, if the input data signal D_0 is present (i.e. $D_0 = 1$) then the light emerges through upper channel of s_7. Because, here two light beams (one coming from CLS and another from input data signal D_0) are present at s_7. The light finally comes to the output Y. If there is no input light signal at D_0 (i.e. $D_0 = 0$), the light emerges through lower channel of s_7. Lower channel has no use in our present multiplexing scheme. This shows that input data signal D_0 can be sent to the output terminal Y when control signals are $A = 0$ and $B = 0$.

Second case: say, $A = 0$ and $B = 1$ (i.e. no light is supplied to A but light signal is supplied to B). In this case light from CLS reaches only to s_6 through T-2. Now, if the input data signal D_1 is present (i.e. $D_1 = 1$) then light emerges through upper channel of s_6 as two light beams are present here. The light finally comes to the output Y. If there is no input light signal at D_1 (i.e. $D_1 = 0$), the light emerges through lower channel of s_6. This shows that input data signal D_1 can be sent to the output Y keeping control signals $A = 0$ and $B = 1$.

Third case: control signal A is present but control signal B is absent i.e. $A = 1$ and $B = 0$. Light from CLS reaches only to s_5 through T-3. Now, if the input data signal D_2 is present (i.e. $D_2 = 1$) then light emerges through upper channel of s_5 as two light beams are present here. This light finally comes to the output Y. If there is no input light signal at D_2 (i.e. $D_2 = 0$), the light emerges through lower channel of s_5. This shows that input data signal D_2 can be sent to the output terminal Y keeping control signals $A = 1$ and $B = 0$.

Fourth case: let us consider the case where both the control signals A and B are present, i.e. $A = 1$ and $B = 1$. Light from CLS reaches only to s_4 through T-4. Now, if the input data signal D_3 is present (i.e. $D_3 = 1$), then light emerges through upper channel of s_4 as two light beams are present here. The light finally comes to the output Y. If there is no input light signal at D_3 (i.e. $D_3 = 0$), the light emerges through lower channel of s_4. This shows that input data signal D_3 can be sent to the output Y keeping control signals $A = 1$ and $B = 1$.

Above discussion shows that applying the proper control signals, one can send any desired input data to the output channel. In this paper, we have exploited the tree-net architecture for designing a time division multiplexing scheme. Basically, the proposed multiplexer is very much suitable in all-optical digital signal communication. However this scheme can successfully be used in analog communication also. The main advantage of the proposed scheme is that the process is all-optical in nature and bears the inherent advantages of tree-architecture. The scheme can easily and successfully be extended and implemented for higher order (8×1, 16×1, 32×1 and so on) multiplexing scheme. This can be done by proper incorporation of NLM based optical switches, extending the tree and by suitable branch selection. To implement an 8×1 multiplexing scheme (which has eight input data signals, three control signals and one output channel), we have to add other four NLM based optical switches (one at T-1, one at T-2, one at T-3 and other at T-4) and one control signal in tree structure and four more switches at the output plane with which inputs are to be connected. It is important to note that the predetermined values of the intensities of laser light for control signals, input signals and the constant light source are needed to send the optical signal in desired channels. To discuss the feasibility on the practical implementation of the whole scheme described above, it may be said that for exciting the nonlinear phenomenon of the conventional NLMs, a high power laser in the order of megawatt (MW) is necessary. Therefore one may think that the system is very much expensive to be implemented physically. The problem of using a very high power laser can be overcome in two ways. In one way, one can develop such NLMs in the domain of organic or organo-metalic compounds where the value of n_2 is very high. But it needs extensive research. The alternative way may be more suitable. If Q-switching or mode-locking or the both process is adopted then one can easily generate high power laser pulses from ordinary solid state lasers, where each pulse may attain the power in the range of MW. As the whole scheme is a digital system which runs with digital pulses in the input and control stages, so using an ordinary laser beam (whose power is in the order of watt range), we can exploit the tree-net architecture for implementing time division multiplexing scheme. The conventional NLMs then can easily respond to implement the above mechanism by the use of light pulses from the ordinary laser source. Such light pulse requires the pulse duration of the order of 0.1 μs to reach the desired output of MW range. To avoid the diffraction limited problems the cell size of the NLM should be properly selected.

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