Realization of a Photonic Switch in a Photonic Crystal Fiber using Kerr Nonlinearities

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ABSTRACT
The realization of a novel concept of photonic switching using photonic crystal fiber is presented in this paper. With the introduction of Kerr nonlinearity into a photonic crystal fiber, the phenomenon of optical switching has got redefined. The proposed scheme involves that the transmission intensity applied to the fiber can be switched from maximum to minimum with the application of suitable phase difference in between the input and the control signal. All the simulations are implemented by Finite Difference Time Domain method.

General Terms
Nanophotonic Devices and Components, Optical Communication.

Keywords
Finite Difference Time Domain Method; Kerr Nonlinearity; Photonic Crystal Fiber; Photonic Switching.

1. INTRODUCTION
In the early days of switching, an optical switch, used to refer to a piece of circuit switching equipment between fibers and they were actually using electronic switching between them. At every node of switching, the optical signal was to be converted to the electrical form and after the switching mechanism is carried out, it had to be again converted to the optical domain for further transmission of the signal [1]. A photonic switch, on the other hand uses the nonlinear material properties in order to realize the switching up of the signals within the fiber itself. Thus, there is a significant merit of photonic switching over optical switching that there is no need to use any other equipment for the above purpose. So, the loss due to use of connectors will not take part here. Again, as the switching of the signal is done inside the fiber itself while in transmission, the time taken by some other devices to perform switching is avoided. Hence, it increases the switching speed and also the circuit complexity is reduced.

A great deal of work have been done in the field of switching in order to fabricate or construct a device which will perform switching operation without the need of conversion of the optical to electrical and electrical to optical domain. Various applications of these optical switches are optical cross connects, protection switching, optical add/drop multiplexing, optical signal monitoring, and network provisioning. The techniques to design these switches are electromechanical switches, microelectromachanical system devices, electro-optic switches, thermo-optic switches, digital optical switches, liquid crystal switches, bubble switches, acousto-optic switches and semiconductor optical amplifier switches [1]-[4].

In reference [5], the authors have used pump-probe technique and transmission measurement technique to study the all optical switching (A-OS) and optical limiting (OL) behavior of pthalocyanines and metallopthalocyanines materials. In reference [6], the input light is incident in one port and is diverted to the two output ports which is both in the right and left in a T junction switch. In reference [7], a photonic crystal structure is used to behave as a switch by introducing Kerr nonlinearity into the dielectric rods. The switching of the state of the signal is realized for the phase differences of $\pi/2$ rad and $-\pi/2$ rad. Again, in reference [8], a self switching mechanism is narrated using SOAs and MZI phenomenon, where the intensity switches from minimum interference to maximum interference for the phase differences of $\pi/2$ rad. The switching mentioned here is that, the input signal is distributed unequally over the two interferometer arms. As a result, a nonlinear phase difference is induced and which leads to a increase in the intensity.

In this paper we have proposed a novel method of optical switching in a glass-air hole photonic crystal fiber [9]-[14]. The Kerr nonlinearity is introduced into the air hole region to realize the switching [13]. The values of Kerr nonlinearity are varied in order to get the required result. The results obtained are compared with the output signals obtained from a PCF without using nonlinearity.

2. REALIZATION OF THE OPTICAL SWITCH
The photonic crystal fiber, as shown in the Fig 1, is of the length of 1.5 µm, with a radius of 0.55 µm. The air holes are arranged in a circular crystal lattice array and are having the radius of 0.03 µm. The radial distance between the two consecutive air holes is 0.08 µm. The air holes are arranged in six concentric circles. An input signal S and a control signal C, which is the phase shifted signal of the input, are applied at one end of the fiber. At the other end of the fiber the transmission intensity is recorded.

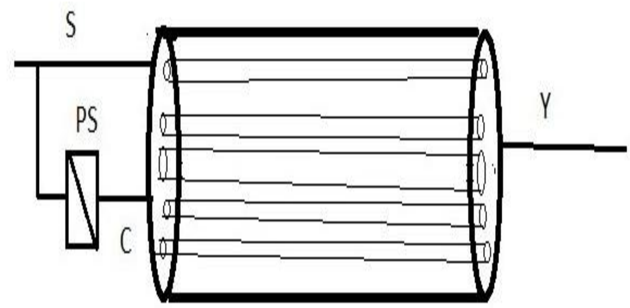
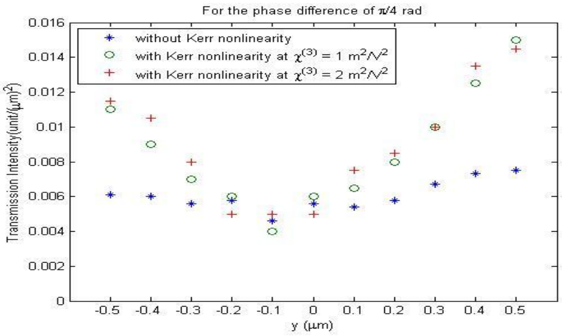
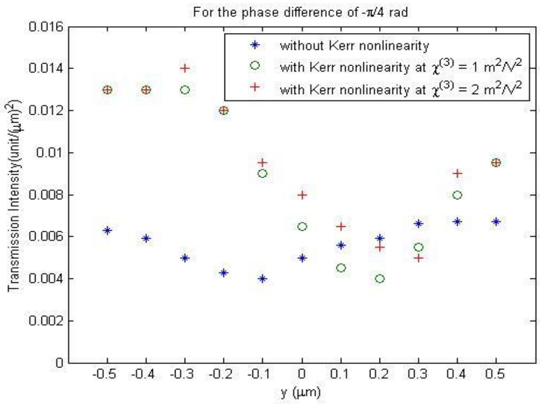


Fig 1: The schematic diagram of the photonic crystal fiber used as an switch. (a) the input source S and the control signal C are incident to the fiber, (b) PS is the phase shifter, (c) Y is the observed output.

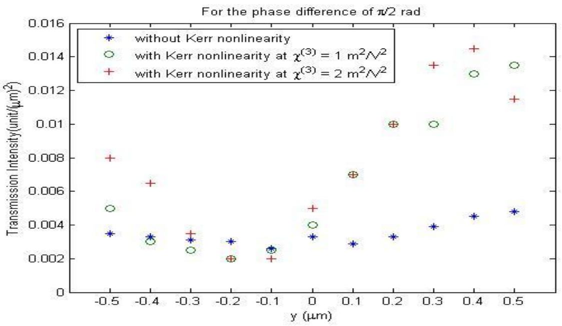
3. SIMULATION RESULTS



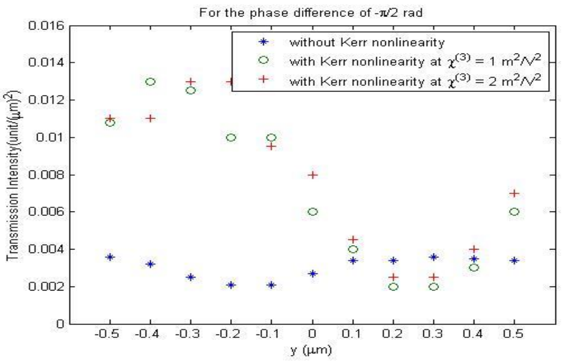
(a)



(b)



(c)



(d)

Fig 2: Comparison between the intensities of the output signals of the fiber with and without applying nonlinearity for the phase differences of (a) π/4 rad, (b) –π/4 rad, (c) π/2 rad and (d) –π/2 rad.

We have simulated the above structure in three ways; (a) without applying the nonlinearity, (b) applying the Kerr nonlinearity at (i) $\chi^{(3)} = 1\ m^2/V^2$ and (ii) $\chi^{(3)} = 2\ m^2/V^2$. The phase differences applied are π/4 rad, -π/4 rad, π/2 rad and -π/2 rad. The transmission intensity at some equidistant point are recorded for each of the cases and compared.

From Fig 2, it is seen that by applying Kerr nonlinearity the intensity level of the output has got doubled or more than that as it was in the case of the intensity level which we get in the fiber without applying any nonlinearity. Again, if we measure the intensities at each of the equidistant points of 0.1 we can observe that though it is comparable but strictly speaking the intensity for $\chi^{(3)} = 2\ m^2/V^2$ is more than that of the intensity at $\chi^{(3)} = 1\ m^2/V^2$. Hence, out of the above three cases we get the intensity variation for the case of nonlinearity applied for $\chi^{(3)} = 2\ m^2/V^2$. The differences of intensities at each equidistant point for the inversion of the phase are shown in the table:

Table I. Comparison of the Difference of Intensities

Difference of Intensities Between the Phase Differences of		π/4 rad and –π/4 rad		π/2 rad and –π/2 rad	
$\chi^{(3)}$ (m^2/V^2)		*1*	*2*	*1*	*2*
Observed Difference of Intensities (unit/(μm)^2) at Length (μm)	*-0.5*	0.002	0.0015	0.0058	0.003
	-0.4	0.004	0.0025	0.01	0.0045
	-0.3	0.006	0.006	0.01	0.0095
	-0.2	0.006	0.007	0.008	0.011
	-0.1	0.005	0.0045	0.0075	0.0075
	0	0.0005	0.003	0.002	0.003
	0.1	0.002	0.001	0.003	0.0025
	0.2	0.004	0.003	0.008	0.0075
	0.3	0.0045	0.005	0.008	0.011
	0.4	0.0035	0.0035	0.01	0.0105
	0.5	0.0015	0.005	0.0075	0.0095

The above table states that, for the phase differences of π/2 rad and –π/2 rad and at the points -0.2 and 0.3 the difference of the intensities are maximum and also they are inverted to each other. Hence, we can say that the switching of the intensities occurs for the phase differences of π/2 rad and –π/2 rad.

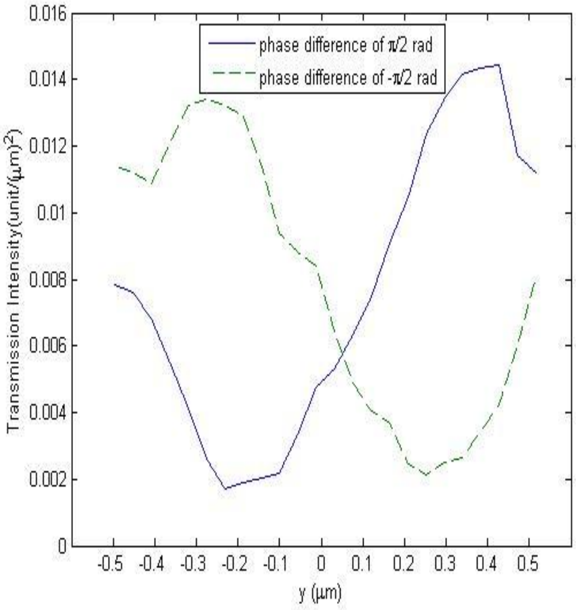


Fig 3: Comparison of the output of the photonic crystal fiber for the phase differences of π/2 rad and –π/2 rad with kerr nonlinearity at $\chi^{(3)} = 2\ m^2/V^2$.

From Fig 3, we found that the switching occurs at the point 0.25 µm on either side of the center.

4. CONCLUSION

In this paper a photonic switch is realized in a photonic crystal fiber using Kerr nonlinearity. It is found that the switching of the intensity from maximum to minimum occurs as the phase difference between the input signal and control signal changes from π/2 to –π/2.

5. REFERENCES

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