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A NEW SCHEME OF INCREASING THE INHERENT PHASE CHANGE OF A LIGHT PASSING THROUGH AN OPTICAL KERR TYPE OF NON-LINEAR MEDIUM USING MULTI-PASSING TECHNIQUE

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Abstract

Optical communication is tremendously used in modern communication system because of its high degree of parallelism to control a large amount of data transmission of very high speed, low loss, low bit error rate and many other advantages. Optical Kerr type of non-linear material shows 2nd order non-linearity. Due to this non-linear property, when an intense light signal propagates through the Kerr type of non-linear material, there is found a change of refractive index occurred at the material which leads to the phase modulation of the propagating light signal. In this paper, the authors propose a new scheme to increase the inherent phase change of the light signal propagating through the Kerr type of non-linear medium by passing the light signal multiple times through the medium.

Keywords: *Optical Kerr Medium, Multi-passing techniques, Phase Change of light.*

1 Introduction

The optical Kerr effect has so many applications in optical switching, optical self-focusing and defocusing, optical digital signal processing, etc.[1]. When an intense light signal propagates through a 2^{nd} order non-linear Kerr material, the refractive index of the material changes with the intensity of the carrier light signal and the phase modulation of the light signal occurs [2-5]. Many research works have been done in the area of optical data processing computation using the non-linear Pockels and Kerr materials. High amount of phase difference is created by using several techniques like different cutting technique or multi-passing technique by reducing the half-wave voltage ($V\pi$) of the electro-optic material [6-11].Quantum square root of Controlled Z gate, quantum phase shift gate, programmable single qubit gates are developed by using the intensity and phase encoding technique of light by M. Mandal et. al using the electro-optic Pockels materials [12-14]. All-optical frequency encoded NOT based latch by using Semiconductor Optical Amplifier, binary addition with massive use of non-linear material based system, all-optical digital matrix multiplication scheme with non-linear material are also established by several scientists [15-17]. Powers of the sideband frequencies are increased by decreasing the intensity of the central frequency are studied both for Pockels and Kerr materials [18-20]. Pockels cell based intensity modulation, measurement of electrical parameters of the passive electronic elements, intensity and voltage controlled phase switching are developed by using the electro-optic Pockels and Kerr cell by Lakshan et. al. [21-23]. Quadratic electro-optic effect [24], controlling of second harmonic generation by using the enhanced Kerr electro-optic effect [25], Kerr electro-optic effect in liquid crystals [26] are established by several scientists. The reliability and sensitivity of the Kerr electro-optic field is measured with high voltage pulsed transformer oil by X. Zhang et.al [27].

All-optical high frequency clock pulse generator with Kerr material is developed using the feedback mechanism in Toffoli gate by S. Dey et al [28]. All-optical Kerr material based optical switches are developed for cryptographic encoding of binary data by S. Biswas et al [29]. Different quantum controlled gates are established by using the Kerr material [30-32]. Single photon, two photon or multi-photon polarization controlled gates are established using the cross Kerr non-linearity [33-35].

The all-optical Kerr effect leads to the very fast optical switching of the order of pico-second or sub-pico second time scale which has so many applications including microscopy and spectroscopy [36-37]. Frequency conversion, binary to decimal conversion, secured cryptographic communication etc are performed very nicely by using the Kerr type of non-linear materials [38-40].

The main objective of the paper is to increase the inherent phase of the light signal passing through a Kerr type of non-linear medium by using the multi-passing technique.

2 Multi-passing technique

It is a technique by which a light wave is passing through a crystal for many times in a suitable way. To develop such a technical system, we have used mirror, beam splitter, beam coupler and filters. In proper arrangement of the mirror an incident light beam after passing the non-linear medium is again made feedback through the crystal again with the help of three mirrors. The multi-passing technique is depicted in our proposed scheme. There are so many advantageous on applying such technique on the non-linear Kerr medium. As the light ray suffers so much interaction with the Kerr material for multiple times propagation, so it can gain its optical path length in its phase term. Finally, there is found an increase of the phase by the active use of the multi-passing technique successfully.

3 Use of multi-passing technique for increasing the phase change of light passing through a Kerr medium

In the proposed scheme the multi-passing technique is used. To achieve such a scheme fruitfully, three identical mirrors (M_1, M_2 and M_3) are taken in the proper orientation. An incident optical beam having sufficient intensity initially passes through a beam splitter as well as the non-linear Kerr medium carrying the non-linear property. Here, the incident light beam is consisting of the two optical beams with two different intensities and different frequencies ($\upsilon_1$andυ_2). After emerging from the Kerr material, the light wave is passing through a filter for selective frequency filtering, and then it will again pass through the crystal with active use of the three mirrors. Before entering into the non-linear Kerr medium, the light beam is again combined with another intensity light beam of other frequency just emitted from another beam splitter. This feedback mechanism through the material for multiple times is unidirectional i.e. the direction of the output light beam through the material is always from the left to right. As the optical beam with a particular combination of the frequency is propagating through the Kerr medium multiple times, so it will gather so much optical length. Because of the increase of the intensity of the light by the intensity of the other frequency (υ_2), this will directly increase the phase of the optical beam.

4 Theoretical analysis

When the high intense light signal passes through a Kerr non-linear medium, then the refractive index of the medium is changed with the intensity of the propagating light signal. This change in refractive index of the Kerr medium is expressed as

$$n = n_0 + n_2 I$$

Where, n_0 is the constant refractive index and n_2 is the non-linear correction term of the Kerr material. $I$is the intensity of the propagating light signal.

In the proposed scheme two specified models are described. In the first representing model (Figure 1) the light wave with the intensity I_1 and with frequency $\upsilon_1$being combined with another light wave with intensity $I_2$with frequency υ_2 are passing through the Kerr material of length 'l' gives the final output.

In the first proposed scheme (Fig. 1) the expression of the electric field of the output light wave becomes

$$E(l) = E_0 \cos(\omega t - knl)$$

$$= E_0 \cos\{ \omega t - k(n_0 + n_2 I)l\}$$

$$= E_0 \cos\{\omega t - kn_0 l - kn_2(I_1 + I_2)l\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Here, the Phase change occur between the incident light wave and the final output light wave (Eq^n 1) becomes

$$\delta_1 = \mathrm{k}n_0 l + kn_2 l(I_1 + I_2)$$

$$= kl\{(n_0) + n_2(I_1 + I_2)\}\ldots\ldots\ldots\ldots\ldots(2)$$

The expression of the electric field of the output light beam after single passing through the Kerr material is

$$E(l) = E_0 \cos(\omega t - knl)$$

$$= E_0 \cos\{\omega t - k(n_0 + n_2 I)l\}$$

$$= E_0 \cos\{\omega t - kn_0 z - kn_2 \left(I_1 + \frac{I_2}{2}\right) l\}\ldots\ldots\ldots\ldots(3)$$

The above light wave (Eq^n 3) is again passing through the Kerr material for the second time(Fig.2) gives the expression of the electric field

$$= E_0 \cos\{\omega t - 2kn_0 l - 2kn_2(I_1 + I_2)l\}$$

$$= E_0 \cos\{\omega t - 2kn_0 l - 2kn_2 I_1 l - 2kn_2 I_2 l\}\ldots\ldots\ldots\ldots(4)$$

The phase retardation developed between the incident light wave and the final output light wave (Eq^n 4) becomes

$$\delta_2 = 2\mathrm{k}n_0 l + 2kn_2 l(I_1 + I_2)$$

$$= 2kn_0 l + 2kn_2(I_1 + I_2)\}\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Now the final phase retardation between the above described two models (Fig.1 and Fig.2) i.e. between (Eq^n 2) and (Eq^n 5) is

$$(\delta_2 - \delta_1) = \mathrm{k}n_0 l + kn_2 l(I_1 + I_2)$$

Using a suitable compensator, the intensity independent term can be removed. So, finally the phase retardation is expressed as $(\delta_2 - \delta_1) = kn_2 l(I_1 + I_2)$

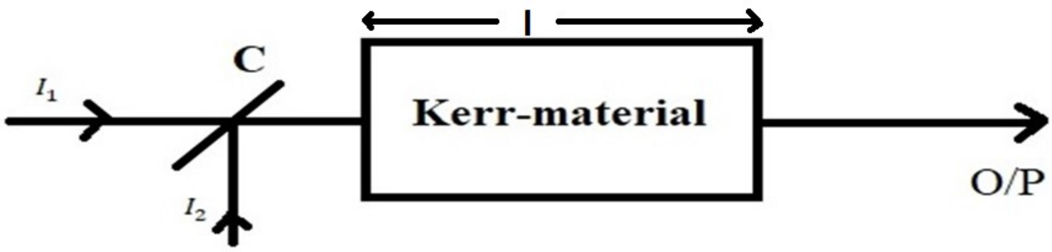

Figure 1 Schematic diagram of the light wave single passing through Kerr medium.

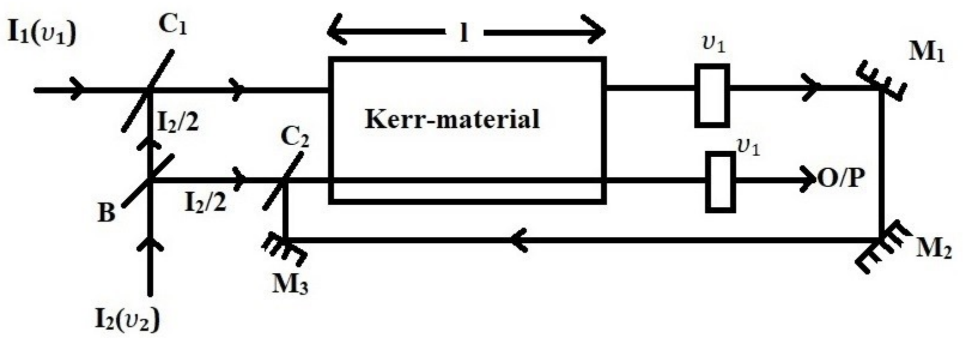

Figure 2 Schematic diagram for the light wave is passing two times through nonlinear Kerr medium;C_1 , and C_1 are beam coupler, M_1, M_2, and M_3 are mirrors, B is beam splitter

5 Results and Discussion

One can get a massive phase change of an incident light wave by introducing the multi-passing technique in scheme 2. For a fixed value of the input intensity I_1 if one can combine the another intensity I_2in the two successive passing with the help of a beam splitter, filter and also the three mirrors then a high degree of phase retardation is achieved. For the 1[st]scheme, the phase developed between the input and the output light wave is comparatively small in comparison to the phase developed in the scheme 2.

Taking, λ= 800nm, $n_2 = 0.35 \times 10^{-19} m^2/watt$, l= 5cm, the phase change with the variation of the intensity I_2 for a fixed value of the intensityI_1 = 5 × $10^{13} watt/m^2$ is shown in the Table 1

$I_2(10^{13} watt/m^{2})$	$(\delta_2 - \delta_1)$
1	0.8247
2	0.9621
3	1.0995
4	1.2376
5	1.3744
6	1.5119
7	1.6493
8	1.7867
9	1.9242
10	2.0616

Table 1 Variation of the phase retardation $(\delta_2 - \delta_1)$ with the Intensity (I_2) of frequency υ_2

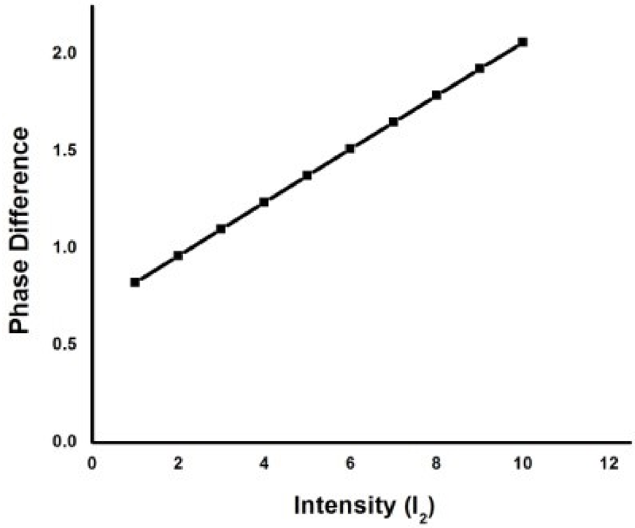

Figure 3 variation of phase difference$(\delta_2 - \delta_1)$ with intensity I_2

The variation of the phase retardation$(\delta_2 - \delta_1)$ with the variation of the intensity I_2 is shown in the Figure 3. It is seen that the phase difference between the output signal of the described schemes (scheme 1 and scheme 2) increases linearly with the increase of the intensity I_2.

6 Conclusions

In the above scheme the light signal passes multiple times through the Kerr material which leads to increase the inherent phase of the light signal. The amount of phase retardation for the 2nd time passing of the light signal is doubled in comparison to the single time passing of the light signal through the Kerr material. Using this technique, one can achieve high amount of phase retardation of the output signal. The whole process is all-optical, so the speed of operation of the system is very high.

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