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All optical alternative approach of conducting NAND and NOR logic gates with phase encoding principle

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ABSTRACT

All optical logic gates are the most important building blocks for conducting all optical digital and analog signal processing and computing. It has several uses in the high speed communication system. In last few years various non-linear properties of semiconductor optical amplifier have been utilized for realization of all optical logic gates exploiting different type's optical modulations. In such connection optical phase encoding technique drew more attention in last few years as it shows higher receiver sensitivity and extended tolerance limit in long-haul fiber transmission systems. In this communication the authors have proposed an alternative approach for conducting all optical logic gates with phase encoded inputs by the exploitation of the four wave mixing (FWM) property in semiconductor optical amplifier (SOA).

1. Introduction

In last few decades optics has proved its strong potentiality against the increasing demand of increasing bandwidth and super fast speed of operation in data as well as in image processing. All optical logic gates are the main key elements in all optical signals processing and computing. These logic gates basically perform the necessary functioning at the nodes of network such as data encoding and decoding, pattern matching, recognition and various switching operation [1–3]. All-optical logic gates have already been proposed and experimentally demonstrated by means of several procedures based on fiber nonlinearity, semiconductor optical amplifier (SOA), ultra fast non-linear interferometer (UNI), and periodical poled $LiNbO_3$ (PPLN) etc. [4–11]. Various non-linear properties of SOA are the recent interest in optical switching due to its low power level requirement in logic operation, very fast switching response and easier integration character in photonic integrated circuits (PIC). Several encoding/decoding formats have already been implemented for the realization of different all optical logic gates. Every scheme of encoding has some own limitations. The most important limitation in frequency encoding is its conversion efficiency. The alternative technique is to encode the phase of the signal instead of its frequency. Phase encoding shows improved receiver sensitivity and high tolerance limit in long-haul transmission systems through non-linear optical fiber [12,13]. Therefore uses of phase encoding can give a high spectral efficiency in both optical communication and computing. In last few years wavelength divisions multiplexing (WDM) has been projected to meet the growing demand of data transfer rate. Again four wave mixing in SOA can strongly support much higher speed of operation than any other conventional schemes. As because it is an intraband process so it requires a shorter scattering time. Therefore to achieve high speed of processing or highly and spectrally efficient communication it will be better to choose FWM in SOA with phase encoding/decoding formats [14,15]. Some research groups have already proposed and experimentally demonstrated the XOR logic with the phase encoded inputs implementing FWM in SOA [16–18]. Here in this communication the authors propose a new scheme of developing all optical logic gates using FWM in SOA with the support of phase encoded inputs and outputs.

2. Principle of phase encoded operation in the FWM process through SOA

Four-wave mixing is an important third order intraband nonlinear effect in SOA. In this process three electromagnetic waves interact with one another inside SOA and the output wave comes out after the interaction. If we consider FWM in SOA by three input waves, where two of them function as pump waves oscillating with field amplitudes E_{P1} and E_{P2}, with frequencies ω_{P1} and ω_{P2}, and initial phases ϕ_{P1} and ϕ_{P2} respectively, and the third one is the signal wave with amplitude E_S, frequency ω_S and phase ϕ_S. Due to four-wave mixing in SOA, the FWM generated wave will emerge with frequency ω_{FWM} and phase ϕ_{FWM}. Let us consider that all these waves are co-polarized along the *z* axis and propagating along the *x*-axis for an efficient FWM in SOA. Therefore in general the four-wave

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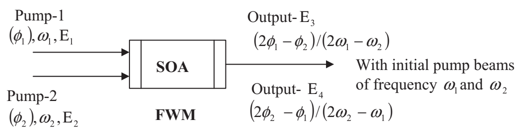

Fig. 1. Self pumped four wave mixing in SOA.

mixing output in non linear media has the form,

$$E_{FWM} = E_{P1}E_{P2}E_S\eta\, Cos\,[(\kappa_{P1} + \kappa_{P2} - \kappa_S)x - (\omega_{P1} + \omega_{P2} - \omega_S) + (\phi_{P1} + \phi_{P2} - \phi_S)],$$

where η represents the factor of conversion efficiency. Therefore the output wave will come out with frequency $\omega_{FWM} = \omega_{P1} + \omega_{P2} - \omega_S$ and phase $\phi_{FWM} = \phi_{P1} + \phi_{P2} - \phi_S$.

But when two beam incident over SOA instead of three, then the input signal also act as pump waves. This is self pumped FWM and its output has the form given by,

$$E_{4,3(FWM)} = C\,E_{1,2}E_{2,1}^2 Cos\left[(2\kappa_{2,1} - \kappa_{1,2})x - (2\omega_{2,1} - \omega_{1,2}) + (2\phi_{2,1} - \phi_{1,2})\right],$$

where C is the conversion factor in this process. Therefore there are two simultaneous FWM outputs with frequency $\omega_3/\omega_4 = (2\omega_1 - \omega_2)/(2\omega_2 - \omega_1)$ and phase $\phi_3/\phi_4 = (2\phi_1 - \phi_2)/(2\phi_2 - \phi_1)$. The self pumped four wave mixing is shown in Fig. 1.

So the self pumped FWM between two beams produce two side-bands with the unmodified pump beams. If the pump beams having intensity E_1 and E_2, with frequency ω_1 and ω_2 and phase ϕ_1 and ϕ_2 respectively. Then due to FWM in SOA there are two sidebands, one has intensity E_3 with phase $(2\phi_1 - \phi_2)$, frequency $(2\omega_1 - \omega_2)$ and the other with intensity E_4 having phase $(2\phi_2 - \phi_1)$ and frequency $(2\omega_2 - \omega_1)$.

3. Optical phase encoding mechanism for conduction of all-optical logic gates

There are several types of data encoding/decoding schemes which are already reported by many groups of researchers for developing the optical logic gates, e.g. spatial encoding, intensity encoding, wavelength and frequency based encoding, polarization encoding etc. Phase encoding mechanism has high spectral efficiency than the other encoding schemes because of its high receiver sensitivity and improved nonlinear tolerance of fiber. Here a signal can be called a '0' bit if it has no phase difference with respect to a reference signal whereas a signal can be called '1' bit if it ensures a 'π' phase change with respect to the same reference signal. Due to stability in periodicity of phases in this encoding scheme, the output the phase difference value 2π and −π are equivalent to 0 and π phase difference respectively. It is important to say that all the signals '0' and '1' have the same frequency, wavelength, state of polarization, intensity, etc. This characteristic feature is therefore very much helpful over the other conventional encoding processes used in both communication and computation, as at both the logic states (0 and 1) the signal gets equal power which is independent of frequency, polarization and intensity.

4. Proposed scheme of all optical NAND/AND and NOR/OR logic gates

In this paper we have proposed a new scheme of phase encoded all optical AND/NAND logic with the help of self pumped FWM in SOA. The arrangement of this proposed scheme of all optic logic is shown in Fig. 2. In this arrangement at first two continuous wave comes out from a multiplexer of nearly zero dispersion wavelength having frequency ω_1 and ω_2. The light wave with frequency ω_1 is

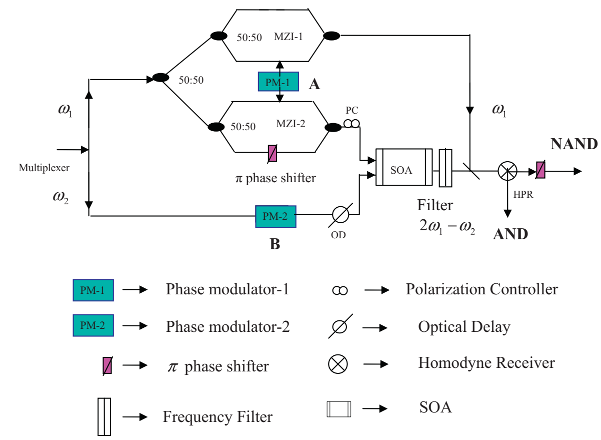

Fig. 2. Schematic diagram of proposed all optical phase encoded NAND and AND logic gates.

split equally into two beams and these two equally intense beams enter into MZI-1 and MZI-2 separately. The desired phase of the input signal can be generated by placing a phase modulator over the light wave path. Here the one input signal [**A**] of desired initial phase ϕ_1 is to be placed simultaneously in the lower arm of MZI-1 and the upper arm of MZI-2 using phase modulator-1 (PM-1) and the other input [**B**] of initial phase ϕ_2 is to be placed over light wave path with frequency ω_2 at a proper position by phase modulator-2 (PM-2). Here the phase modulator will generate a relative phase difference π or 0 according to the data given for logical processing. A π-phase shifter has to be placed at the lower arm of MZI-2 also. At the output of MZI-1 and MZI-2, the wave will come out or not will depend on the phase relative to the reference and it depends also on the nature of interference taken place at the output coupler of these MZI's. Now the wave from the output of MZI-2 is to be entered inside SOA to act as one of the pump wave-1 for FWM and the other pump wave-2 enters from PM-2.

Therefore the self pumped FWM process will start inside SOA due to the presence of these two beams. According to the theory of phase operation of FWM in SOA, the output waves will appear with the frequencies $(2\omega_1 - \omega_2)$ and $(2\omega_2 - \omega_1)$ with phases $(2\phi_1 - \phi_2)$ and $(2\phi_2 - \phi_1)$ respectively. A frequency filter is placed at the output of SOA so as to remains only one wave of frequency $(2\omega_1 - \omega_2)$ with phase $(2\phi_1 - \phi_2)$.

In the absence of any of these two beams, the FWM in SOA will not occurs and as a result no output wave will appear. At last the output of the filter is fed at the final output of the logic gate. Again the output of MZI-1 is also connected at the final output for the realization of the logic. Both the pump waves are co-polarized for efficient FWM in SOA by placing the polarization controller (PC) and the time is aligned properly by introducing an optical delay in the line. Again in this arrangement the wave appeared from the output coupler of MZI-1 is also supplied at the final output for the realization of the logic in some cases.

4.1. Realization of AND/NAND logic

If $\phi_1 = 0$ i.e. the inputs signal A is in phase with the reference phase. Since the wave in both the arm of MZI-1 are in the same phase $\phi_1 = 0$, so due to constructive interference at the output coupler of MZI-1 the wave will emerged from MZI-1 and linked to the final output of the gate. Due to the placement of π phase shifter in the lower arm of MZI-2, then the waves in the arms will meet in out of phase at the output coupler of MZI-2. Hence no wave will come out due to destructive interference and thus the FWM will not take place in the absence of pump beam-1 in spite of presence