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All- optical phase encoded 4-to-1 phase multiplexer using four wave mixing in semiconductor optical amplifier

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ABSTRACT

Optics has already showed its potency over its electronic complements in case of superfast computing and communication systems. Semiconductor optical amplifier, (SOA) with its several nonlinear properties, plays a very crucial role in the development of high-speed all-optical processor. Multiplexer and demultiplexer are the extremely important element of the processor which takes part in utilizing different actions like encoding, decoding, routing, and the different process of data conversion and generation, etc. In this paper, the authors have proposed a scheme of phase encoded all-optical phase multiplexer using four wave mixing (FWM) property of semiconductor optical amplifier. Thus, the improved tolerance against fiber-nonlinearity and higher receiver sensitivity of phase encoding method with the fast occurring processes like FWM in SOA offers higher speed in this proposed scheme of multiplexing.

1. Introduction

In the last few decades all-optical processing has proved its strength through its different inherent properties like parallel processing ability, less crosstalk, and energy efficiency of the passive components [1,2]. The use of nonlinear property of semiconductor enhances the prospects of the development of all-optical processor [3–5]. The multiplexer is an important part of the processor which can be used in case of variety of data processing like encoding, decoding, routing, converting, generating, and constructing a simple design of the network etc. In general a multiplexer is constructed by the combination of different logic gates. So it is a combinational logic unit. A multiplexer is a device which selects data from one input channel out of many input channels and to transfer it to a single output with the help of triggering signals. In a binary multiplexer, there are n triggering inputs (selector) required for multiplexing the data from 2^n input channels to the single output. Thus, the binary 4-to-1 multiplexer has four input channels and two triggering inputs which are essential to select one of the input channels for transferring the data to the output. In case of construction and implementation of all optical multiplexer, various encoding techniques have been already proposed and demonstrated [10–13]. In the last few years, phase encoding technique drew more attention to the researchers as it shows higher receiver sensitivity and extended tolerance against nonlinearity of the fiber used for signal transmission systems. Thus, phase encoding in optical computing gives higher spectral efficiency [6–9]. However, four wave mixing (FWM) in SOA requires a very short scattering time because it is an intra-band process. Therefore, to accomplish high speed of multiplexing it will be better to choose FWM in SOA with phase encoding procedure. In this report, the authors have proposed a scheme of phase encoded 4-to-1 phase multiplexer using the FWM property of SOA. Here, in this phase encoded 4-to-1 phase multiplexer, the phase information of the four input channels (ϕ_{c1}, ϕ_{c2}, ϕ_{c3}, and ϕ_{c4}) is transferred to the output (ϕ_{ci}, i = 1,2,3&4) with the help of two phase encoded triggering selector inputs (ϕ_A and ϕ_B) which is shown in Fig. 1. Thus, this proposed all-optical phase encoded multiplexer may follow the above demand of high speed processing.

2. Method of phase encoding

Various encoding and decoding techniques have already been reported by different group of researchers to develop a proper all-optical processor. To design and implement the fast and reliable

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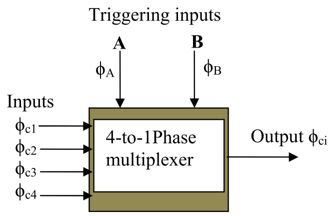

Fig. 1. Phase encoded phase multiplexer.

all-optical processor, different phase encoding techniques have acquired special interest as it shows higher receiver sensitivity and greater tolerance limit in long-haul fiber transmission systems. In this report, the authors have suggested a simple method of phase encoding where the phase difference value between the input or output light waves with their coherent reference waves are used to designate the binary digits of the system. Here, only the two phase difference value 0 and π radian between the waves are employed in this purpose. The phase difference value 0 and π radian is labeled as a carrier of '0' and '1' bits, respectively, in this phase encoding method. Due to stability of periodicity of phases in this encoding scheme, at the output the phase difference value $2n\pi$ and $(2n \pm 1)$ π (where n is any integer) are equivalent to 0 and 1 bits, respectively [14–17]. In this proposed encoding scheme we can avoid the problem of maintaining the fixed phase against the nonlinearity of the fiber because the phase difference value always remains steady.

3. Proposed interferometric switching arrangement

In this scheme a hybrid interferometric switch (HIS) is proposed by combining two Mach-Zehnder interferometers (MZI) for generating the input pump waves for FWM with the proper phase value according to the data bits applied to the selector input [18,19]. This interferometric switch has two inputs (upper and lower) and two outputs (upper and lower). Here two parallel Mach–Zehnder interferometers are coupled by joining their one of the wave guide arm. This common arm will provide one of the common paths for the propagating light waves coming from the input of both the Mach–Zehnder interferometers (MZI). In this hybrid interferometric switch, a light wave is first split by $1 \rightarrow 2$ Y-branch 3 dB coupler and then entered into the upper and lower input of it where these waves are again split uniformly by $1 \rightarrow 2$ Y-branch splitters and transmitted through both the arms of upper and lower MZI. The light waves are recombined at the $2 \rightarrow 1$ combiner by means of interference of the waves meet at the upper and lower output of the HIS. The interference will be constructive or destructive based on the phase of the light waves by which they superpose with one another at that moment. In case of constructive interference, the light beam will come out with the same phase and frequency by which they interfere with one another and no light for destructive interference. To modulate the phase of the wave, an electro-optic phase modulator (PM) is placed over the common arm of the interferometric switch and this will introduce additional π phase depends on the applied biasing voltage. This phase modulator (PM) is enabled or disabled based on the given binary input data (1,0) through the application of biasing voltage Vπ (half-wave voltage) over it or not. A π phase shifter is also placed in the lower wave guide arm of the interferometric switch which will introduce always extra π phase over the light wave passing through it. The phase of the light waves at the upper and lower outputs of the interferometric switch for the given data inputs is shown in Table 1 and the schematic diagram of it is shown in the Fig. 2.

Thus, the light wave will emerge only from the upper output of the interferometric switch with no phase difference when the binary input is 0 and from the lower output of the interferometric

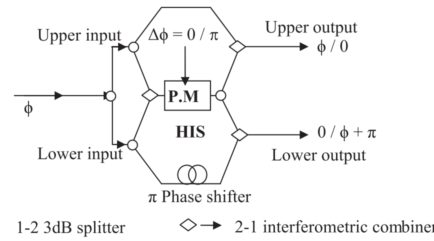

Fig. 2. Schematic diagram of proposed hybrid interferometric switch (HIS).

switch with extra π phase difference when the input is 1. For proper interferometric action at the output combiners of the interferometric switch gives a desired pump waves for FWM in SOA, the phase and amplitude of the superposing light waves must be synchronized by adjusting the tuned optical time delay and variable attenuators.

4. Phase of the FWM sidebands in SOA

FWM is a nonlinear intra-band process in a semiconductor optical amplifier. The phenomena of FWM occurs inside SOA when more than one light waves with different frequency enters into it and as a result of this phenomena, there are many FWM sideband light waves of different amplitudes, frequencies, and phases based on the nonlinearity of it. In case of FWM in SOA, if three waves interact with one another, then two of them act as pump waves and the other as probe generates different idler components with the unmodified inputs also are given by $E_{FWM} = E_1E_2E_3\eta(i,j)\ \mathrm{Cos}[(k_1 \pm k_2 \pm k_3)x-(\omega_1 \pm \omega_2 \pm \omega_3)t + (\phi_1 \pm \phi_2 \pm \phi_3)]$,

where E_i, k_i, ω_i and ϕ_i represents the field amplitudes, wave vectors, frequencies, and phases of the three input light waves (i = 1,2,3) [3,14–17]. Here, consider all these waves in FWM be propagated along the x axis and for efficient FWM they must be co-polarized. After FWM in SOA, the different sidebands come out with different frequencies $\omega_{\mathrm{FWM}} = \omega_1 \pm \omega_2 \pm \omega_3$ and with respective phases $\phi_{\mathrm{FWM}} = \phi_1 \pm \phi_2 \pm \phi_3$ which is shown in Fig. 3. Among all these three wave-supported FWM sidebands, the wave with frequency $\omega_1 + \omega_2 - \omega_3$ is one of the dominant components with phase value $\phi_1 + \phi_2 - \phi_3$ because in this case the agreement with the phase-matching condition is relatively simple.

5. Proposed scheme and operation of phase encoded 4-to-1 phase multiplexer

In this proposed design of all optical phase encoded 4-to-1 phase multiplexer, the selector inputs are produced by the two proposed hybrid interferometric switching arrangements using two different light waves with slightly different frequencies ω_1 and ω_2 which must be nearer to zero dispersion wavelength, i.e., 1550 nm. The phase information is introduced according to the selector inputs A ($\Delta\phi_A$) and B ($\Delta\phi_B$) by the phase modulators PM-1 and PM-2 in the hybrid interferometric switch 1 and 2, respectively. Suppose ϕ_{p1} and ϕ_{p2} are the initial phase of the light waves entering at the inputs of the HIS-1 and HIS-2 respectively. When A = 0 ($\Delta\phi_A = 0$) and B = 0 ($\Delta\phi_B = 0$), then the light wave will only emerge with phase ϕ_{p1} and ϕ_{p2} from the upper outputs and no light wave will appear from the lower outputs of the

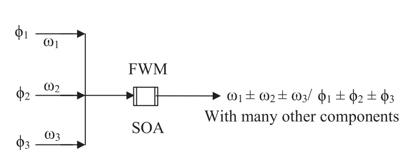

Fig. 3. FWM in SOA, using three inputs.