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A novel all optical method of implementing an *n*-bit wavelength encoded complete digital data comparator using nonlinear semiconductor optical amplifiers

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ABSTRACT

Data comparator is the integral part of arithmetic and logical unit of any electronic or optical data processor. Due to some inherent limitations of electronics it cannot be possible to obtain a super fast operation (over terahertz limit) from electronic comparators. Again wavelength encoding technique has been established as an excellent one over other existing optical data encoding techniques. Semiconductor optical amplifier (SOA) technologies have shown their strong potentiality of realizing many all-optical systems. In this communication the authors have proposed a new scheme of developing all-optical wavelength encoded *n* bit binary comparator exploiting the four-wave mixing, wavelength filtering, wavelength conversion and nonlinear polarization rotation capabilities property of nonlinear semiconductor optical amplifiers. The scheme can be used for comparing signed and unsigned optical binary data of any bit wide numbers as well. The comparator is especially suitable for use as a building block in a larger optical circuit, such as in an all optical telecommunications switch.

1. Introduction

In digital electronic comparators the magnitudes of two binary digits are compared where the binary bits are encoded by the presence (say logic 1) and the absence (say logic 0) of an electrical quantity (either voltage or current). The conventional electronic digital systems have already shown their limitations so far as the speed and parallel processing with a wide range of data are concerned. To overcome these limitations optics has already established its strong potential role in digital information processing, networking, image processing etc. because of its high degree of inherent parallelism. Being of its charge neutrality and no rest mass character photon has proved its superiority as information carrier than electron in the data processors and communication networks. In the very near past telecommunications only transmitted low bandwidth voice and text data (BW ~ KHz), it is now required to transfer video information which has a very large bandwidth (BW ~ MHz). Electronic devices have almost reaching their fundamental limits at such high bandwidth in terms of their power consumption, wiring density and throughput. Very recently computation and communications with ultra high bandwidth approach 200 GB per second or more being implemented by transmitting the information as optical signals, typically in the form of optical packets of information, across the network. To cope with this, the researchers all over the globe engaged themselves to develop an all optical system including optical data comparator, for utilizing the full advantages of the optical bandwidth. Up to now, the implementation of all-optical circuits for pattern matching, i.e., able to determine if two binary numbers are equal or not, is reported by an XOR gate implemented with a nonlinear optical loop mirror in [1]. In [2] it is achieved by combining AND and XOR gates in a single SOA-MZI structure. Martinez et al. reported an all optical *n*-bit comparator by cascading a number of SOA-MZI structures [3]. With this approach, *n*-bit pattern require *n* SOA-MZIs. Yasui et al. exploits differential spin excitation in semiconductor MQW structures [4] to obtain ultra fast all optical pattern matching. In [5], an SOA-based all optical circuit for the comparison of 1-bit Boolean numbers is demonstrated. The all optical subsystems able to deterministic if an *n* bit (with $n > 1$) pattern representing a Boolean number is greater or less than another one reported in [6] based on logic gates exploiting XGM and cross-polarization rotation in SOAs. Again it is also established that in the conventional ways of digital electronic systems, the photonic systems cannot be implemented without any modification. To make a compatible all optical system scientists and researchers from all over the world proposed several direct and indirect schemes for developing the optical information processing system over the last three

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Table 1
Excitation table of a wavelength Encoded optical 2 bit data comparator.

Inputs				Intermediate outputs			Final output
A_1	A_0	B_1	B_0	L	E	G	Y
λ_1	λ_1	λ_1	λ_1		λ_s		λ_s
λ_1	λ_1	λ_1	λ_2	λ_1			λ_1
λ_1	λ_1	λ_2	λ_1	λ_1			λ_1
λ_1	λ_1	λ_2	λ_2	λ_1			λ_1
λ_1	λ_2	λ_1	λ_1			λ_2	λ_2
λ_1	λ_2	λ_1	λ_2		λ_s		λ_s
λ_1	λ_2	λ_2	λ_1	λ_1			λ_1
λ_1	λ_2	λ_2	λ_2	λ_1			λ_1
λ_2	λ_1	λ_1	λ_1			λ_2	λ_2
λ_2	λ_1	λ_1	λ_2			λ_2	λ_2
λ_2	λ_1	λ_2	λ_1		λ_s		λ_s
λ_2	λ_1	λ_2	λ_2	λ_1			λ_1
λ_2	λ_2	λ_1	λ_1			λ_2	λ_2
λ_2	λ_2	λ_1	λ_2			λ_2	λ_2
λ_2	λ_2	λ_2	λ_1			λ_2	λ_2
λ_2	λ_2	λ_2	λ_2		λ_s		λ_s

decades. To implement those schemes several encoding mechanisms have been proposed for representing the optical information. In this connection the intensity encoding, polarization encoding, phase encoding may be mentioned [5–10]. But these coding processes have some inherent problems. To avoid those problems very recently frequency encoding scheme has been established very efficiently [11–16]. The prime beauty of the scheme is that as frequency is the fundamental property of the wave so it can preserve its identity irrespective of the absorption, reflection, transmission during its propagation through different systems as well as communicating media. In this connection we can also refer many works on all optical optoelectronic logic gates and flip-flops using spatial light modulators and optoelectronic transducers. But a number of significant drawbacks of electronic/optoelectronic memory prevent the scientists and researchers to build-up a real life super fast optical/optoelectronic computer. In comparison to these schemes, the proposal for representing binary logic states by different wavelengths of a wave removes a lot of difficulties what one found in other proposed schemes [17–20]. In a similar manner, in this communication we have chosen two different and specific wavelengths λ_1 and λ_2 to represent the binary information '0' and '1' respectively. We also exploited the highly efficient cross gain modulation (XGM) and wavelength conversion property of bulk nonlinear semiconductor optical amplifier (SOA), properly known as four wave mixing (FWM). Many approaches have been proposed to achieve all optical logic functions, based on the nonlinear effects in semiconductor optical amplifier, in optical fibers or in waveguides. Particularly, all optical logic gates based on the nonlinear effects of SOAs such as cross gain modulation (XGM), cross phase modulation (XPM), four wave mixing (FWM) and cross polarization modulation are promising as SOAs exhibit high gain in optical power, strong change of refractive index and therefore suitable for photonic up gradation [21]. It should be parallel mentioned here that such properties are independent of polarization and also insensitive to the wavelength of the input data, provided if it is conducted within the SOA gain bandwidth limit [18,19,22–24,25,26]. This can be controlled by the intensity of the pump beam. Moreover, since the FWM effect is used, our propose scheme of digital comparator can provide an ultra fast operation [27].

In this paper, authors propose several all optical subsystems based on a single unit which is capable of producing three different optical signals indicating three data conditions which are greater than, less than and equality conditions. The bit comparison unit can be constructed using several SOAs functioning in different ways. In our system two laser pump beams of wavelength λ_1 and λ_2 are used as logic '0' and logic '1' respectively. In addition to these two pump beams a probe signal beam of wavelength λ_s is also applied to the input of the nonlinear SOA. The beauty of our proposed scheme is that it is capable of comparing signed as well as unsigned binary streams encoded in the optical domain. The system can provide memory efficient as well as time efficient operation. The combinational as well as sequential systems are constructed using the same building block. For simplicity the conventional excitation table of the 2-bit comparator is given in Table 1, where *A* and *B* denote the inputs which are wavelength encoded to be compared and *L*, *E* and *G* represent three possible intermediate outputs (analogous to electronic counterpart). In our system we have combined the three different intermediate outputs to get the final output. The final output wavelengths have the meaning as follows: the output signal of wavelength λ_s represents the equality condition, the wavelength $\lambda_1(0)$ represents the less than condition and finally the wavelength $\lambda_2(1)$ represents the greater than condition of the two binary bit streams. This is advantageous compared to electronic comparators which have three different output channels. This can easily be extended to 3, 4 and up to *n* bit wavelength encoded binary number comparison as well.

2. Working principle

The basic principle of operation of our proposed binary optical comparator system depends mainly on different nonlinear properties of the SOA. The four main principles involve are (i) the four wave mixing in nonlinear SOA, (ii) Principle of wavelength routing using optical ADD/DROP multiplexing, (iii) Principle of wavelength conversion by RSOA, (iv) Principle of wavelength conversion using nonlinear rotation of the state of polarization by SOA.

2.1. *Four wave mixing in nonlinear SOA*

Four-wave mixing (FWM) is basically a third order nonlinear coherent process where the dielectric polarization in a medium depends on the product of three electric fields. The induced polarization leads to the creation of new frequency components of the electric field. SOA controlled FWM can be used to construct wavelength converters [26]. The basic scheme is comprised of one CW probe laser beam of wavelength λ_s and two modulated probe input laser signals of wavelengths λ_1 and λ_2 respectively injected into an SOA. The FWM process in the amplifier gives rise to a new conjugate signal that is absolutely a spectrally inverted replica of the input probe signal [23,24]. For an efficient FWM in an SOA, the polarization states of the pump and the probe beams essentially are identical. There are two different FWM depending upon the co-