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All - Optical AND Gate Using XPM Wavelength Converter

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By using an XPM (Cross Phase Modulation) wavelength converter, an all-optical AND gate, which is one of six fundamental logic gates, has been demonstrated. The wavelengths for probe and pump signals are 1553.8 and 1545 nm, respectively. First, characteristics of the XPM wavelength converter have been studied. When both probe and pump signals are driven by high power, the output power of the XPM wavelength is high. Based on this fact and the experiment, the all-optical AND gate has been proved. Probe and pump signals are transformed to pulse signals by using Mach-Zehnder modulator, which is induced by a pulse generator. Square pulse signals that are similar to the format of NRZ signals have been generated. By coupling two pulse signals into the XPM wavelength converter, AND characteristic is substantiated.

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I. INTRODUCTION

Recent trends, show that demands for the high-speed operation of systems are rapidly increasing. However, the operation of various systems under silicon-based technology is facing the gigantic barriers of limited speed and uppermost boundary of information handling capacity. Compared to silicon-based electronic devices, the InP-based optical device is a key enabling technology for overcoming the current obstacles. Designing any electronic system without mentioning the importance of the six logic gates is meaningless. The optical device cannot be the exception to this fundamental truth. The primary goal of our research is to accomplish six basic logic gates based on all-optical operation. Many researchers have reported their own logic gates that are NOR using SOA [1], OR with NOR using ultrafast nonlinear interferometer [2], and XOR using TOAD [3], and so on. However, logic gates using SOA have a problem of extinction ratio degradation. To overcome the problems with extinction ratio degradation, an XPM wavelength converter can be used [4]. Also, even though logic gates using an ultrafast nonlinear interferometer and TOAD have the advantage of high-speed, they are very complex and difficult to integrate with other logic gates. Contrary to these devices, an XPM wavelength converter is compact, stable, and potentially independent of polarization and wavelength [5]. Therefore, an XPM wavelength converter is employed to embody the basic logic functions. So far, an AND function using an XPM wavelength converter has not been demonstrated. Therefore, AND logic using XPM is performed in this experiment.

II. OPERATIONAL PRINCIPLE OF AND GATE

The schematic of the XPM is shown in Fig. 1. Basically, the primary task of the XPM is wavelength conversion. SOA (3) experiences a change in carrier density when two signals (probe signal with λ_1 and pump signal with λ_2) are counter propagating through it. Due to the change in carrier density, the refractive index in SOA (3) is modified and thus phase change occurs. Signals from SOA (4) and SOA (3) are coupled together to form a phase difference. The output

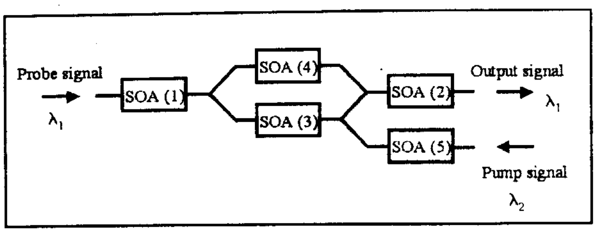

FIG. 1. Schematic of Cross Phase Modulator (Alcatel 1901 ICM).

power is maximized when the phase difference between two signals is 0. This phenomenon is called constructive interference. Also, a phase difference of π results in destructive interference and causes minimum output power. Somewhat periodic state occurs when the probe signal, pump signal, and currents applied into the SOAs are varied [6]. As a result, typical performance of the XPM wavelength converter can be obtained.

By using the concept above, the all-optical AND gate can be realized. A Fixed probe signal is applied while the pump signal is varied. For realizing the all-optical AND gate, only the positive slope in Fig. 2 is utilized. When the power of the probe signal is high, output power moves along the positive slope. Thus, high power of the pump signal results in high power of the output. When the power of the pump signal is lowered, output power moves downward along the slope and thus results in low power. When the power of the probe signal is low, the output signal seems to be turned off since it is very small compared to the output signal induced by high power of the probe signal. By combining the facts mentioned above, the AND gate can be obtained. The truth table is shown in Table 1 for verification of the AND gate.

III. EXPERIMENTS

An all-optical interferometric wavelength converter (Alcatel 1901 ICM) has been used for this experiment. First of all, the input power-output power characteristics of the XPM wavelength converter are attained. The probe signal, which is continuous wave with the wavelength of 1553.8 nm, is applied at -10 dBm and 0 dBm. Also, the power of the pump signal with the wavelength of 1545 nm is ranged from -10 dBm to 9 dBm. The reason for using two different wavelengths is to prevent possible crosstalk, which causes the degradation of signals in the XPM wavelength converter [5]. The currents applied through five SOAs are varied to meet optimized conditions. Fig. 3 shows the probe output power as a function of the pump input power. When the high power of probe signal is coupled into the XPM wavelength converter, the power of the output signal increases as the power of the pump signal increases. Also, when the low power of probe

TABLE 1. Truth table for AND gate.

Probe signal	*Pump signal*	*Output*
Low power(0)	Low power(0)	Low power(0)
Low power(0)	High power(1)	Low power(0)
High power(1)	Low power(0)	Low power(0)
High power(1)	High power(1)	High power(1)

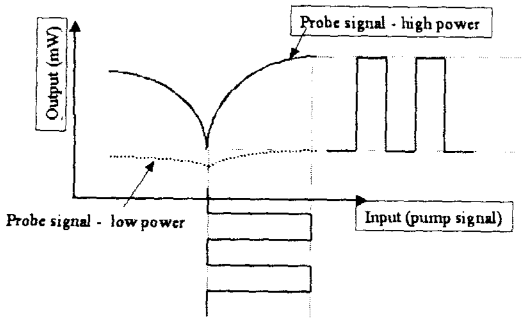

FIG. 2. Operational principle of the all-optical AND gate by using XPM.

signal passes through the XPM wavelength converter, the power of the output signal seems to be turned off. Therefore, the AND characteristic is proved. Operation of the AND gate is fully covered in Section 2. The experimental setup is shown in Fig. 4. The pulse generator has been connected to a Mach-Zehnder modulator so that the Mach-Zehender modulator converts two signals to pulse signals, which depend on the waveform of the pulse generator. Square pulse signals that are similar to NRZ format have been generated. It is more advantageous to use NRZ signals since the present optical transmission systems prefer to use NRZ format data rather than RZ format data to reduce the bandwidth requirement of the system hardware [7]. The modulation frequency in this experiment is about 2.5 MHz. The NRZ signals are combined together in front of the Mach-Zehnder modulator so that signal A and B have the same modulation depth. Power loss occurs since only half of the signal is transferred through a 50:50 coupler. An insertion loss caused by the Mach-Zehnder modulator is about 8 dB. Also, there are insertion losses in other components. Therefore, an EDFA (Erbium-Dope d Fiber Amplifier) is exploited to pull the power of the shrun-

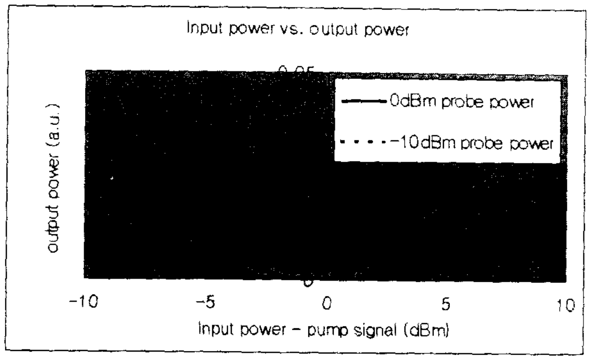

FIG. 3. Input power vs. output power.

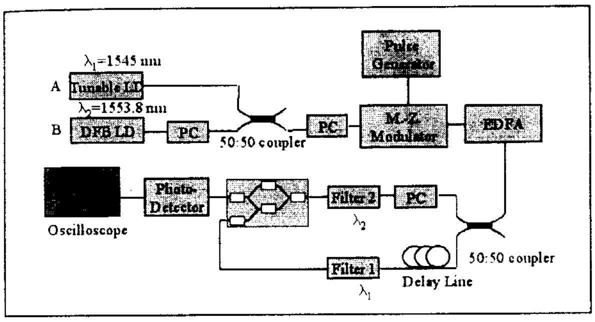

FIG. 4. Experimental setup.

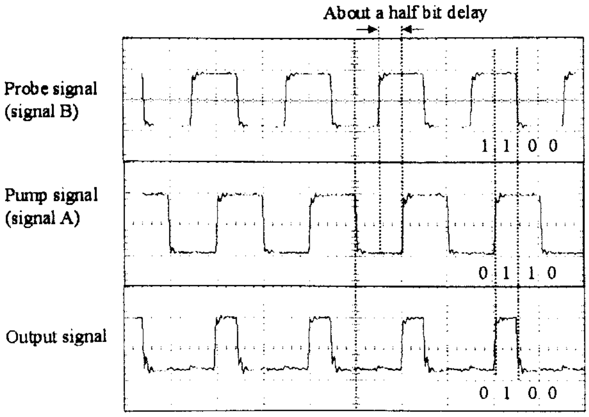

FIG. 5. Input and output signal.

ken signal up to the required level. After dividing the single signal (A + B) into two separate signals, a delay line is used for one arm to achieve a half bit delay of the signal. By using filters, signal A (λ_1 = 1545 nm) and signal B (λ_2 = 1553.8 nm) are obtained. Signal A and B are coupled into the XPM wavelength converter to procure the AND gate signal. It is detected by a photo-detector, and displayed on an oscilloscope. The modulation depth of both pulse signals is about 6 dB. Binary information is represented as signals in either one of two recognizable states. The manipulation of binary information is done by logic circuits called gates [8]. Even though the power level for signal A and signal B is different, signal A and signal B represent significant binary logic levels. Therefore, regardless of power level, a logic AND gate can be obtained if both signals have binary information of logical 1 [9]. Input signal A, signal B, and output signal C are displayed in Fig. 5. Signal A is a half bit delayed in comparison with signal B. The output signal is the overlapped part of signal A and signal B. Pattern of 1100 (signal B) was coupled with pattern of 0110 (signal A) to form the output of 0100. Therefore, the all-optical AND gate has been successfully demonstrated at 2.5 Mb/s. The restriction factor on the speed is the pulse generator (Hewlett Packard 8165 A programmable signal source) because it generates a stable and defined square waveform at about 2.5 MHz. Even though this all-optical AND gate works under 2.5 Mb/s, there is a clear possibility that performance can be enhanced up to 5 Gb/s in NRZ data format. The design of an interferometric wavelength converter mostly employs several SOAs. The only difference for various interferometric wavelength converters is how the SOAs are arranged. Thus, the typical transition time of the XPM wavelength converter used in this device is not much different from other usual interferometric wavelength converters. The typical transition time of the wavelength converter is about or less than 100 ps [10]. Usually, typical transition time is mostly governed by gain recovery time. If the repetition time of the input signal is supposed to be about 200 ps, the all-optical AND gate can work up to 5 Gb/s in NRZ data format. Therefore, it is possible to realize a high-speed all-optical AND gate by utilizing a signal generator which can generate much higher frequency NRZ data. This experiment should be a fundamental gateway for higher speed all-optical logic gates.

IV. CONCLUSION

The all-optical AND gate has been successfully demonstrated by using the XPM. First, characteristics of the XPM wavelength converter have been studied. When both probe and pump signals are driven by high power, the output power of the XPM wavelength converter is high (one-state). Otherwise, the output power of the XPM wavelength converter is low (zero-state). Based on this fact and on the experiment, the all-optical AND gate has been proved. DFB LD (λ_2 = 1553.8 nm) and Tunable LD (λ_1 = 1545 nm) are used to form probe and pump signals. Two different wavelengths are utilized to prevent possible crosstalk, which causes the degradation of signals in the XPM wavelength converter. Probe and pump signals are transformed to pulse signals by using a Mach-Zehnder modulator, which is induced by a pulse generator. The modulation depth is about 6 dB. Pulse signals that are similar to the format of an NRZ signal have been generated. By coupling two pulse signals into the XPM wavelength converter, AND characteristic is obtained. The experiment has shown the stable and less complex operation for, an AND gate. In the near future, the other logic gates such as OR, and XOR will be explored.

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