A method to implement optical logic AND based on FWM effect of SOA

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Abstract—*The nonlinear effects four wave mixing (FWM) mechanism and characteristics of semiconductor optical amplifier (SOA) were analyzed. Based on this, we proposed a method to implement optical logic AND gate based on FWM of SOA. It was approved that this method is feasible by simulation experiment. The biggest advantage of this method is that it can process higher optical signal due to the FWM effect without being limited by the carrier recovery time in SOA.*

Keywords- SOA; FWM; AND；Optical logic gate

I. INTRODUCTION

First of all, to have wide-bandwidth communications, the switching technologies must be improved. Electronic technology no longer will be adequate where the speed of conventional computers is achieved by miniaturizing electronic components to a very small micro-size scale so that those electrons need to travel only very short distances within a very short time. The goal of improving on computer speed has resulted in the development of the Very Large Scale Integration (VLSI) technology with smaller device dimensions and greater complexity. But VLSL technology is approaching its fundamental limits in the sub-micron miniaturization process. Further miniaturization of lithography introduces several problems such as dielectric breakdown, hot carriers, and short channel effects. All of these factors lead to a seriously degrade device reliability. Therefore, a dramatic solution to the problem is needed.

Light is immune to electromagnetic interference because of its ability of traveling at high speed without charging or interacting of its photons with each others. Consequently, light beams can pass through one another in a full-duplex operation with wavelengths in order of 1 micron. A higher bandwidth capacity and a transmission of a massive amount of information over a beam are obtained.

Optical data processing can be done much easier and less expensive in parallel that can be done in electrons. Parallelism is the capability of the system to execute more than one operation simultaneously. Then the parallelism associated with fast switching speeds would result in staggering computational power. A computation that might take more than eleven years by the conventional electronic computer could be performed by an optical computer in only one single hour. Thus the optical-switching technology and the development of optical logic are required to eliminate the optical/electronic conversion. Their operation can scale with the data rate and they have further properties of data regeneration, gain, cascade-ability and implementing more complex operations than possible with a simple switch.

Optical swapping and optical computing are the core unit to achieve all optical signal processing in future all optical networks, they all based on optical logic gates, which are core devices to implement optical swapping system and the key factor of decision network performance. Among the all logic devices ,the optical logic AND gate is a necessary part in all-optical signal processing, can be used in all-optical clock recovery, all-optical demultiplexing, all-optical label extraction, etc. The current study of AND mainly concentrated in the use of optical fiber and SOA nonlinear effect. The nonlinear effect of optical fiber is weak, so that the logic gates based on nonlinear effect of optical fiber will achieve idea effect only by high power input signal or long fiber. In the AND gate based on SOA, one kind is using nonlinear effect cross gain modulation (XGM) of SOA implementation, which has the advantages in simple structure and easy to integrate, but signal process rate is low, so the potential is not big; Another kind is based on SOA assisted with interferometer, which can divided into all-optical logic gate based on SOA-integration interferometer and all-optical logic gate based on SOA-Optical Fiber interferometer. The logic gate which realized by SOA-interferometer structure has the advantages in small size and easy to integrate and only need a small input power can cause the nonlinear effect. The disadvantages of this method is due to limited by carrier recovery time in the SOA, the output pulse will be broaden, the speed of signal processing will be limited, and the spontaneous radiation of SOA will inevitably introduce the spontaneous emission noise. Taking the nonlinear effect advantage of SOA can realize many kinds of optical logic gates, but the design scheme to realize AND gate is relatively less, for example, using two-level SOA's cross gain modulation effect implementing AND gate, using Mach-Zehnder interferometer based on SOA implementing AND gate, etc

In this article, we proposed a method to implement optical AND logic gate based on the analysis of work principle and characteristics of FWM in SOA. We successfully demonstrated logic operation AND. The biggest advantage of this method is not limited by carrier recovery time in the SOA, can deal with higher rate optical signals [1-6].

II. PRINCIPLE

FWM effect in SOA refers to the two different wavelengths of light entered into SOA, often viewed as pump light which wavelength is λ_1 and probe light which wavelength is λ_2, carrier in SOA will form a carrier grating according to the distribution of the incident light intensity. If carrier response fast enough and the efficiency of the carrier are stable, otherwise the efficiency of formed grating will drop. When the pump and probe light are travelling wave and the pump power is greater than the probe light, they spread in the SOA can produce transforming light which wavelength is $2\lambda_1 - \lambda_2$ and idle light which wavelength is $2\lambda_2 - \lambda_1$ respectively. These wavelengths of light signal intensity can be measured by spectral rate. When the pump power is higher than the probe light, the signal produced by FWM which wavelength is $2\lambda_1 - \lambda_2$ will have higher power. If I_1 and I_2 are the light signal intensity which wavelength are λ_1 and λ_2 respectively, the intensities of the signals at wavelengths $2\lambda_1 - \lambda_2$ and $2\lambda_2 - \lambda_1$ are proportional to $I_1^2 I_2$ and $I_1 I_2^2$ respectively. Transforming light intensity is greater than idle light, can be used as the wavelength conversion output [4-11].

To test the FWM effect of SOA, experimental schematic diagram was shown in Fig. 1. Laser-1 generated pump light which wavelength was 1550 nm, laser-2 generated probe light which wavelength was 1552 nm, coupled by a 2×1 coupler and entered into SOA, filtered out with Gaussian filter at the output of SOA. Pump power is about 7.5 dB; probe power is about 4.3 dB in experiment.

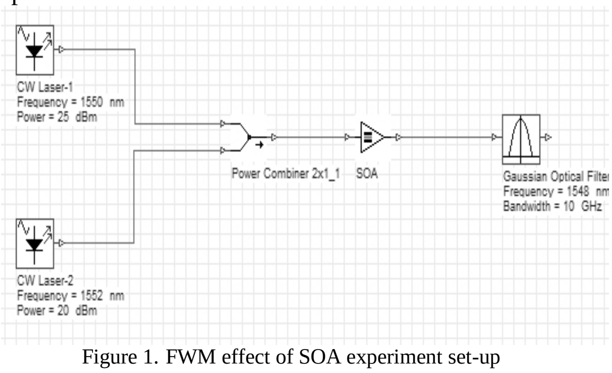


Figure 1. FWM effect of SOA experiment set-up

As shown in Fig. 2 is FWM experiment output spectrum. The pump and probe signals have high intensity. The additional low intensity signals on the spectrum are due to FWM process. It can be seen that transforming light power is greater than idle light.

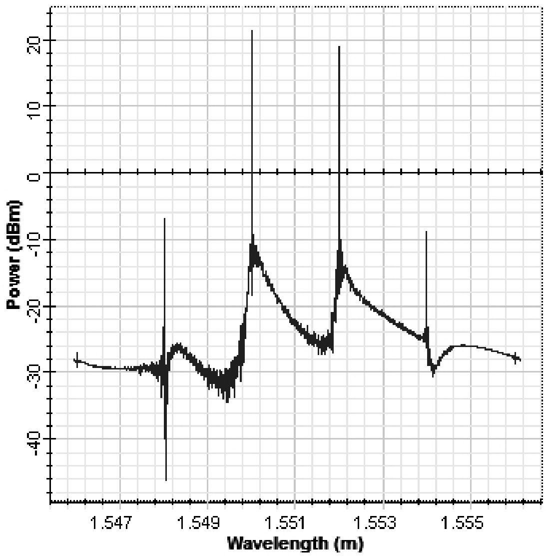


Figure 2. Output Spectra of FWM

As shown in Fig.3 is the curve that the output transforming light power changed with input pump light power. It can be seen by the curve that FWM output transforming light power is increased with the increase of input pump light power, but further increasing the pump light power will lead to the generation of cross gain modulation (XGM) which will suppresses the output of transforming light. The probe light power is less than pump light. It is unfavorable for FWM when the power difference is large between pump light and probe light. Generally 3 - 8 dB power difference will not significantly change the output transforming light power.

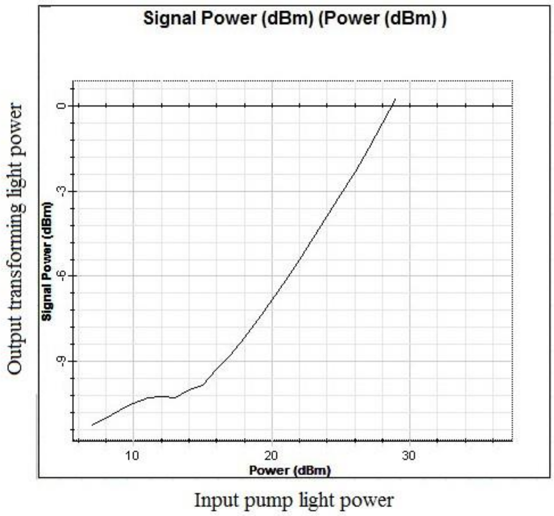


Figure 3. The curve of FWM output transforming light power changed with input pump light power

Another parameter that affects the FWM power is the wavelength separation between the pump and the probe light. As shown in Fig.4 is the curve that the output transforming light power changed with wavelength separation between the pump and the probe light. The pump light power is 7.5dB and the probe light power is 4.3dB in experiment. Under the condition of unchanged pump light wavelength at 1555nm, and changed the probe light wavelength, making the wavelength separation $\lambda_d =$

$\lambda_1 - \lambda_0$ are -6nm, -4 nm, -2 nm, 0 nm, 2 nm, 4 nm, 6 nm respectively. It can be seen that the FWM power is high if the wavelength separation is small. It also shows that the curve is asymmetric viz. for a give$\lambda_d = \lambda_1 - \lambda_0$, the FWM signal power is higher for $\lambda_d > 0$ than that for $\lambda_d < 0$[7-11].

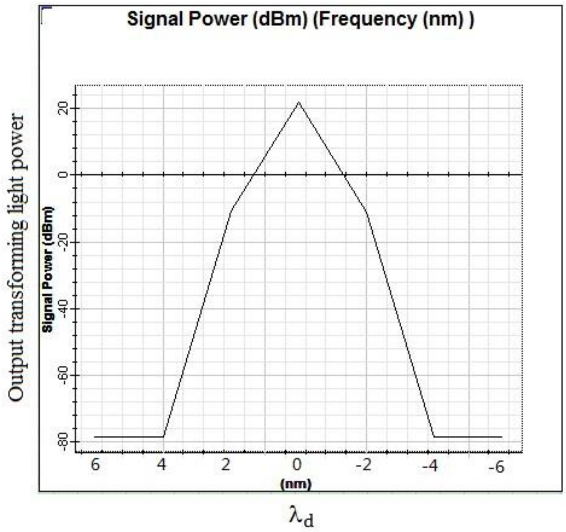


Figure 4. The curve of FWM output transforming light power changed with wavelength separation between the pump and the probe light

When two light signals A and B enter into SOA, which wavelengths are $\lambda_1$and λ_2 respectively and the power of signal A is larger than signal B. According to the principle of the generation of FWM, the new frequency lights will generate only when both the signal A and B are "1". The wavelength of new frequency lights are $2\lambda_1 - \lambda_2$and$2\lambda_2 - \lambda_{12}$. It will not generate new frequency lights in any other situations. If we use filter to filter the new frequency lights which wavelength is$2\lambda_1 - \lambda_2$, the output result happens to be the result of AND logic output between A and B.

III. EXPERIMENT

As shown in Fig.5 is the schematic diagram of AND function implement based on FWM of a single SOA. The continuous-wave laser-1 generated continuous light which wavelength is 1550nm.The 10Gbit/s signal A is loaded to the continuous light through amplitude modulation. The pulse sequence of A is: 1100. The continuous-wave laser-2 generated continuous light which wavelength is 1552nm.The 10Gbit/s signal B is loaded to the continuous light through amplitude modulation. The pulse sequence of B is: 0110.the signal A and B is coupled by a 2×1 coupler and entered into SOA. A Gaussian filter is placed at output of SOA, which central wavelength is 1548nm.The power of signal A is 15dB, the power of B is 10dB, the injected current of SOA is 300mA.

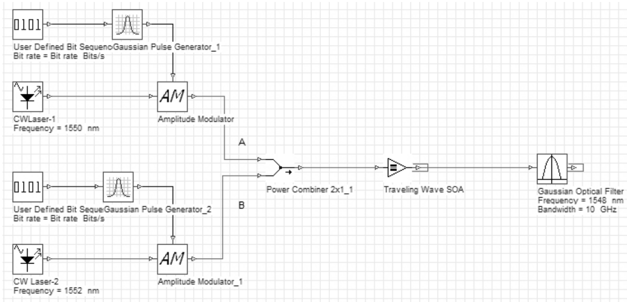
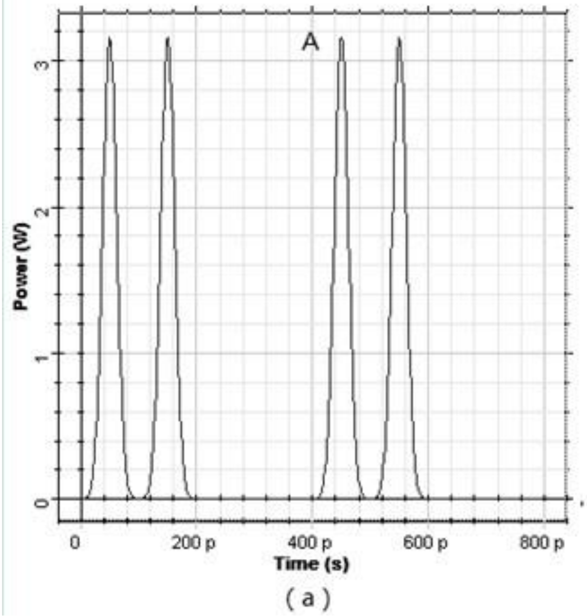
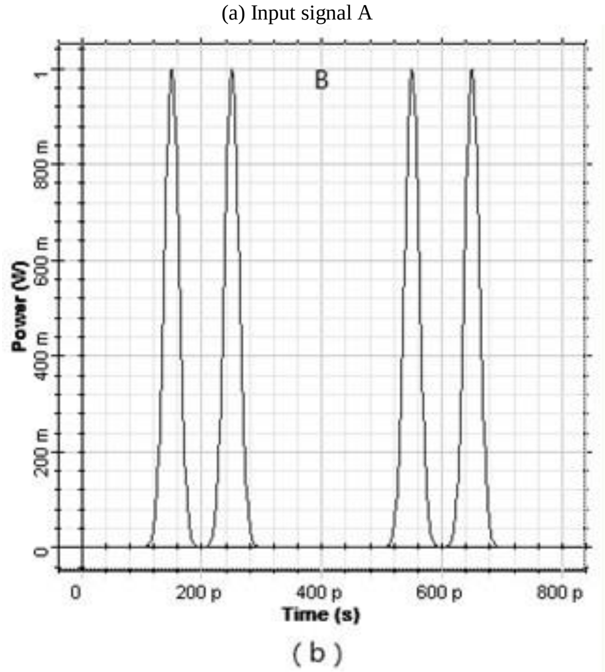


Figure 5. Schematic diagram of experimental set-up

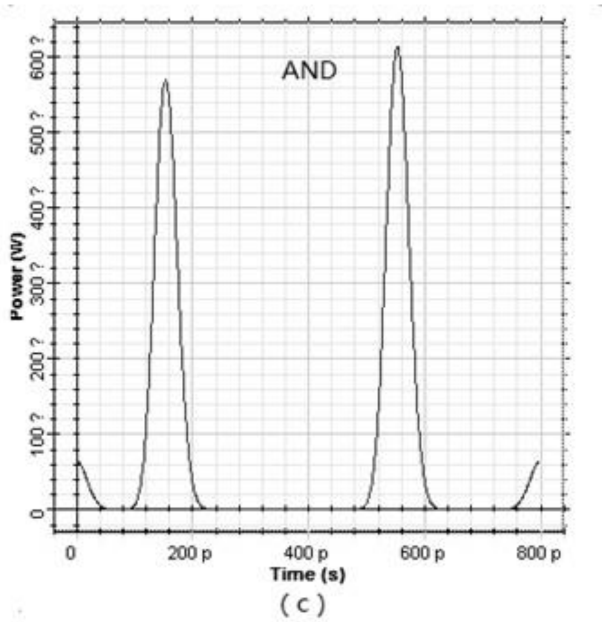
The output results are shown in Fig.6. The input signal A is shown in Fig.6 (a), the input signal B is shown in Fig.6 (b), the output of AND is shown in Fig.6 (c). The output is: 0100 consistent with the theoretical value. It measured that the output signal power is -20dB.



(a) Input signal A



(b) Input signal B



(c) Output signal of AND

Figure 6. Experiment results

IV. CONCLUSIONS

We analyzed the FWM mechanism and characteristics of SOA and demonstrated an all-optical logic AND gate based on FWM of SOA. The biggest advantage of this method is not limited by carrier recovery time in SOA and has the potential to operate at higher signal rate. The shortcoming of this method is the output power is low.

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