ALL-OPTICAL TRIODE USING DUAL-STAGE WAVELENGTH CONVERTER IN ERBIUM DOPED FIBER AMPLIFIERS

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1. Introduction

All-optical switching is expected to have wide applications in the field of communication and computation due to its capability of handling large bandwidth signals and large information flow. For example, the third order nonlinear optical effect is used to obtain optical switching devices. However, this requires a laser source of very high energy above the order of MW/cm^2, which is a fundamental limitation. Commercially available erbium-doped fiber amplifiers (EDFAs) have already established their key role in 1.5μm optical communication networks. It is necessary to demonstrate an all-optical device as the transistor in electronics before the optoelectronics can be developed [1-5]. In this study, the laser induced signal enhancement (LISE) effect, in which optical signals are amplified while maintaining an almost constant modulation degree when a continuous wave (CW) laser is injected into the erbium-doped fiber amplifier (EDFA), was observed using two 1.5μm lasers. Moreover, a dual-stage wavelength converter is carried out using two EDFAs and optical filters. The first of the two stages is based on cross-gain modulation in the EDFA whereby conversion from an input wavelength (1534 nm) to a bias wavelength (1555 nm) is accomplished. The 1555 nm-wavelength is converted back to 1534 nm in the second stage. An all-optical triode was demonstrated using the same wavelength.

2. Experimental Setup

Figure 1 shows a block diagram of the optical triode. The three tunable laser diodes consist of a single-facet antireflection-coated Fabry-Perot laser diode. The desired wavelengths are selected by tuning the angle of the high-diffraction-efficiency grating used as an external mirror in the cavity. The typical spectral linewidth is 1 MHz.

The optical modulation intensity of the 1534 nm-wavelength laser (I_{in}) was obtained using electro-optics modulators and signal generator. The modulation degree of the laser intensity is defined as $M = 100x(I_{max} - I_{min})/(I_{max} + I_{min})$ (%), where I_{max} and I_{min} represent the maximum and minimum intensities of the laser, respectively. Both the modulated 1534 nm-laser (I_{in}) and the CW 1555 nm bias laser (I_{bias}) were fed to the EDFA-1 using an optical coupler. The Er-doped fiber used in the EDFA was 20 m long, the core diameter was 2.3 μm, and the doping density of Er was 1700 ppm. Two EDFAs have a maximum gain of 35 dB at 1535 nm. Two tunable band pass filters (spectral half-width: 1 nm) of the central wavelength of 1555 nm (F-1) and 1534 nm (F-2) were placed after the EDFA-1 and EDFA-2, respectively. The incident and transmitted laser intensities were measured using photodetectors and an oscilloscope.

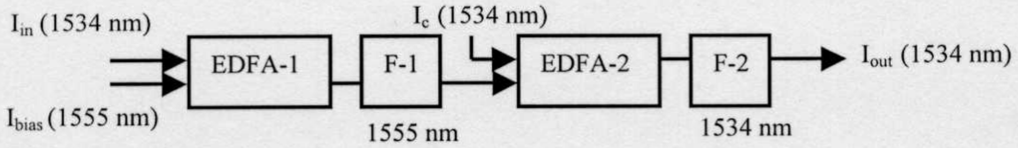
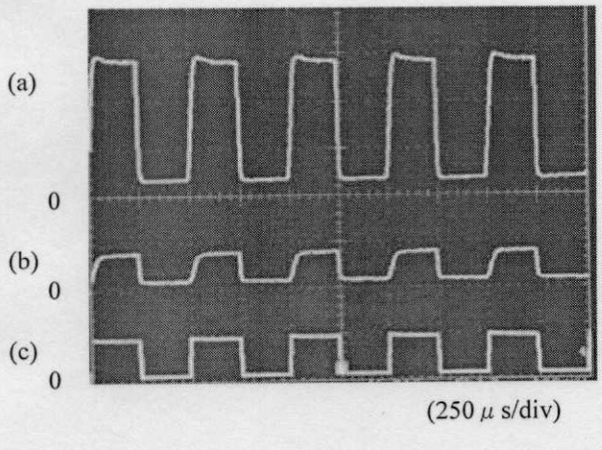


Fig. 1. Block diagram of the optical triode.

3. Experimental Results

Figure 2(a) and 2(b) show the changes in the output laser intensity (I_{out}) when the control lasers (I_c = 8 and 0 μW, respectively) are injected into the EDFA-2. Figure 2(c) shows the changes in the input laser intensity (I_{in}) when the modulation frequency is 1 kHz and the modulation degree is 90%. The input and CW bias power is 60 and 6 μW, respectively. The vertical axis is scaled in arbitrary units. For I_c = 8 μW, the output power is measured at 126 μW and modulation degree is 80%, as shown in Fig. 2(a). For I_c = 0 μW, the corresponding values are 12 μW and 82%, as shown in Fig. 2(b). Thus, the output power is amplified approximately 10 times, while maintaining the almost constant modulation degree. Figure 3 shows the dependence of the output power (I_{out}) on the CW control power (I_c) for several values of the input power (I_{in}) at the CW bias power (I_{bias}) of 6 μW. For I_{in} = 7 μW, the output power increases as the control power increases from 0 to 54 μW. When the input power is increased, the output power increases and shows almost the same behavior for all three cases.



Figs. 2. (a) and (b) Changes in the output laser intensity (I_c = 8 and 0 μW, respectively). (c) Changes in the input laser intensity.

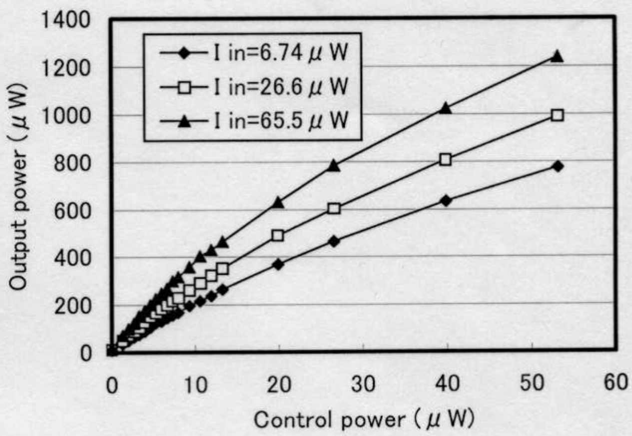


Fig. 3. Dependence of the output power on the control power.

Figure 4 shows the dependence of the output power (I_{out}) on the CW bias power (I_{bias}) for several values of the control power (I_c) at the input power (I_{in}) of 65 μW. For I_c = 7 μW, the output power decreases as the control power increases from 0 to 60 μW. When the control power is increased, the output power increases and shows almost the same behavior for all four cases. Figure 5 shows the dependence of the output power (I_{out}) on the input power (I_{in}) for several values of the control power (I_c) at the bias power (I_{bias}) of 6 μ W. For I_c = 0 μW, the output power is increased from 8 to 18 μW when the input power increases from 0 to 65 μW. For I_c = 7 μW, the output power increases monotonously and reaches 270 μW when the input power increases up to 65 μW. In addition, the output power is increased when the control power increases from 14 to 54 μW, as shown in Fig. 5.

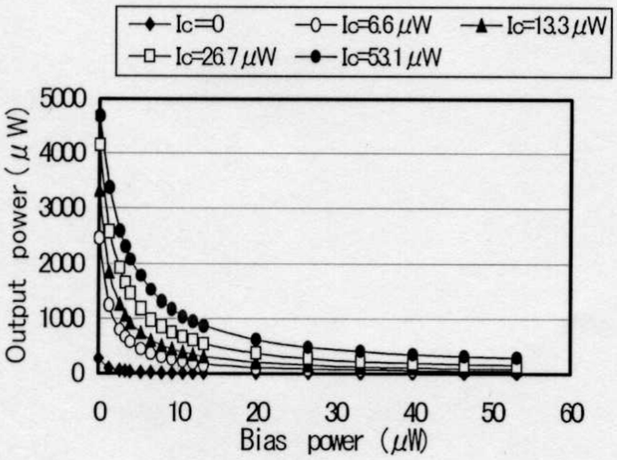


Fig. 4. Dependence of the output power on the bias power.

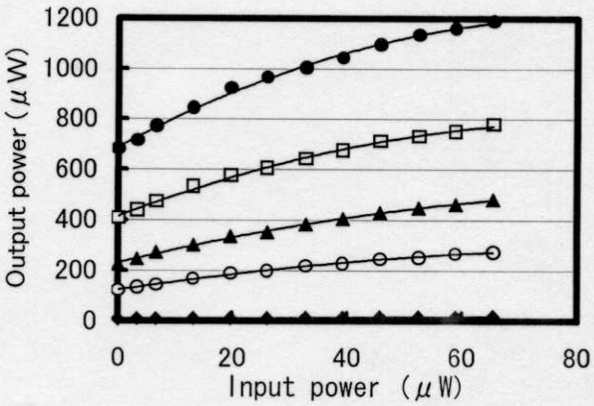
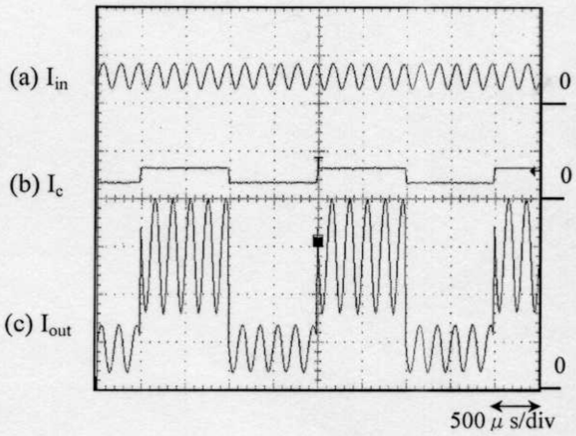


Fig.5. Dependence of the output power on the input power.

Figure 6(a) and 6(b) show the changes in the input (I_{in}) and control (I_c) laser intensities when the modulation frequencies are 5 and 1 kHz, respectively. Figure 6(c) shows the changes in the output laser intensity (I_{out}). The CW bias power is 6 μW. The vertical axis is scaled in arbitrary units. The output signal is amplified and controlled by the control signal.



Figs. 6. (a) Input, (b) Control and (c) Output waveforms

4. Discussions

All-optical wavelength conversion has successfully been demonstrated with semiconductor optical amplifier (SOA) devices exploiting the cross-gain modulation (XGM) effect as well as the cross-phase modulation effect (XPM). In the XGM scheme a strong input signal and a cw signal are introduced into a SOA. The input signal is used to saturate the gain of the SOA and thereby modulates the cw signal carrying the new wavelength. Unfortunately, XGM is accompanied by large chirp and low extinction ratios. In order to overcome these disadvantages, SOAs have been integrated in interferometric configurations, where the intensity modulation of the input signal is transferred into a phase modulation of the cw signal and exploited for switching. These XPM schemes enable wavelength conversion with lower signal powers, reduced chirp and enhanced extinction ratios.

To explain the experimental results and the LISE effect, it is necessary to consider the nonlinearity of amplification in the EDFA, in which the optical signal is amplified while maintaining an approximately constant modulation degree when the CW laser is injected into the EDFA. If the modulated and CW lasers are superposed, the modulation degree ought to decrease due to the CW component to be amplified linearly by the EDFA. However, the experimental results showed that the optical signal was amplified with approximately constant modulation degree, as shown in Fig. 2. It should be noted that the CW control power of 27 μW was greater than the output power of 10 μW at the control power of 0 μW, as shown in Fig. 5. Moreover, amplified spontaneous emission (ASE) was observed 1534 nm passing through the EDFA-2 at the control power of 0 μW. Therefore, the LISE effect can be caused by injecting the stimulated emission, because the change of the spontaneous emissions are enhanced by the CW laser in the EDFA. In order to explain a mechanism of the LISE effect, further detailed experimental and theoretical studies should be conducted by taking into consideration factors such as the transition probabilities and the lifetimes of each energy level.

It has been already observed that the ASE changes inversely with the variation of the incident laser intensity [4,5]. Therefore, the output waveform passing through the F-1 filter changes with the opposite phase of the input. As the waveform passing through the F-2 filter also changes with the opposite phase with respect to that passing through the F-1 filter, the output waveform changes in phase with the input. However, the response frequency (~10 kHz) was limited due to the lifetime of $^4I_{11/2}$ and $^4I_{13/2}$ levels of Er^{3+} in the EDFA. It is necessary to reduce the lifetime of the spontaneous emission. One way to obtain a faster switching speed would be to use a semiconductor amplifier instead of the EDFA.

5. Conclusion

We demonstrated the all-optical triode which has the input and output characteristics in the same manner as the transistor in electronics using low power lasers of the same wavelength. The output signal power was amplified more than 100 times, maintaining an almost constant input modulation degree, when the control laser was injected into the device. It is expected that the characteristics of the device can be improved applying a semiconductor amplifier and promote the realization of an optical computer.

6. References

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