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Noise Figure Characteristics of Wavelength Conversion Using FWM in an SOA Integrated DFB Laser

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1 Introduction

The transparent optical wavelength converter is required as a router at interconnection nodes in WDM optical networking systems. Non-degenerated four-wave mixing (NDFWM), as a coherent optical wavelength conversion, could provide such a switching device by simple configuration [1]. NDFWM in a carrier population inverted semiconductor waveguide such as SOA [2] and DFB laser [3], or in highly nonlinear DSF fiber [4] is extensively studied recently.

The authors had reported very high conversion efficiency by a SOA/DFB integrated device [5]. The device had an in-line pump source to realize single device operation, and it also had very high linear gain which is difficult to attain by a single DFB laser. The achieved efficiency was over 0 dB up to 300 GHz pump-signal detuning and -5 dB at a 1 THz detuning for the case of upward frequency conversion. These attractive results could not directly be tied up with a high performance as switching devices in networking systems. There is necessity to evaluate the S/N characteristics of this device, which is the aim of this paper.

2 Experimental

The integrated device consist of three sections along the wave propagation direction. The center section has corrugation near the active layer, and it acts as the DFB laser. The corrugation depth is set for the κ of $60cm^{-1}$. Whereas the other sections have no corrugations and both facets were coated with anti-reflective films, so they act as SOAs. Each SOA/DFB/SOA region has 250/300/250 μm length, and these sections are electrically separated to be injected a current independently.

The signal wave, generated by a tunable laser, was introduced from a single mode fiber to the device by way of two coupling lens, and the output waves were coupled to a fiber the same way. The signal wave was adjusted to have the same (TE) polarization as the pump wave. Typical input power at device facet was -18 dBm. Our definition of the conversion efficiency is the ratio of the input signal to output conjugate at the device facets.

The noise figure (NF) is a value that indicates the deterioration of the signal to noise ratio, and is a criterion to estimate the noise performance of switching devices, and given for the converter by [6]

$$NF = \frac{2W_{\parallel} + h\nu}{\eta h\nu}, \quad (1)$$

where $W_{\parallel}$ is the ASE power per unit frequency in the same polarization direction of the signal (TE polarization in our experiments), η is the conversion efficiency, and $h\nu$ is the photon energy at the converted wavelength. Noise figure measurement was performed by observing the spectra detected by a well calibrated optical spectral analyzer of 12.5 GHz (0.1 nm) bandwidth.

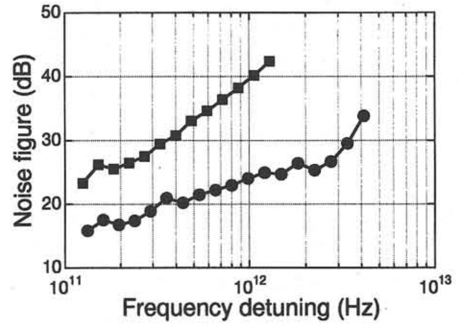

Figure 1: Experimental results of NF with respect to the detuning between pump and signal. The circle (rectangle) is for upward (downward) frequency conversion.

3 Results and Discussion

Figure 1 shows the evaluated NF values of the integrated device for various detuning when the current of 300 mA was injected in the whole device uniformly. A NF of 16 dB at 130 GHz detuning for upward frequency conversion was obtained, and was 24 dB at 1 THz detuning. In the reference [2], a NF of 22.4 dB at 1 THz detuning was reported using 1.5-mm-long SOA. Our result is almost equivalent to this, by using a single device of 800 μm length cavity. This is due to the saturation effect of in-line pump wave which resulted in very low ASE power.

The systematic NF measurements were performed with respect to the injection current to each SOA/DFB sections. Figure 2 is the contour plot of the NF with

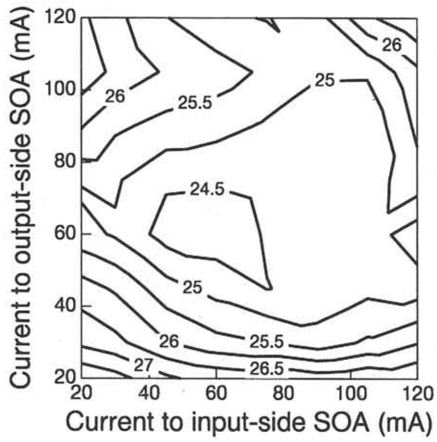

Figure 2: Experimental results of noise figure (dB) with respect to the current in input-side and output-side SOA.

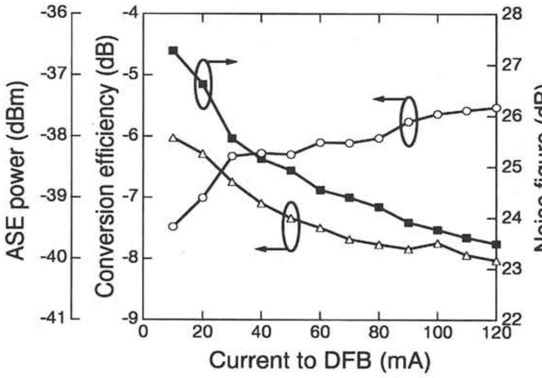

Figure 3: Experimental results of conversion efficiency (open circle), ASE power (open triangle), and noise figure (solid rectangle) with respect to the current in DFB section.

respect to the current in input-side (horizontal axis) or output-side (vertical axis) SOAs. The current in DFB section was fixed to 90 mA, and the detuning between pump and signal was 1 THz. From the figure, we can see that the NF is mainly depends on the output-side SOA's current, and almost independent of the input-side SOA's. Also the NF deterioration was observed for over $\sim$ 70 mA current injection. As the gain saturation affected not only signal power but also conjugate's linear amplification, the conversion efficiency was more rapidly saturated than the ASE power.

Figure 3 shows the conversion efficiency, ASE power, and the NF with respect to the current in DFB section when the current in each SOA sections was fixed to 75 mA, and the detuning was set to 1 THz. A decrease of the ASE for the increase of the current in the DFB section was observed. That is the gain saturation effect due to the increase of the in-line pump power. As a result, the NF characteristics is improved following the increase of the DFB's current.

The authors performed the parameters fitting to above experimental results by calculating the evolution of the field amplitudes using the standard modes coupling formalism [7]. The saturation power of 18 mW,

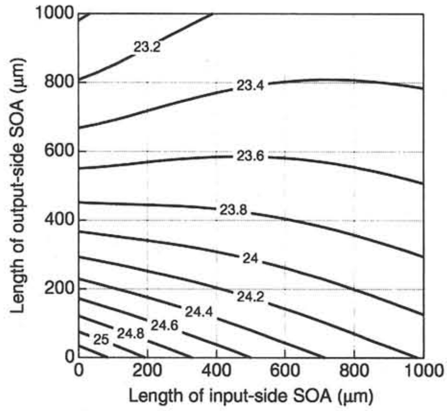

Figure 4: Calculated noise figure (dB) with respect to the input-side and output-side SOA length.

internal loss of 20 cm^{-1}, and χ^3/g_0 of $4.0 \times 10^{-20} m^3/V^2$ were estimated. Using these parameters, simulation of the NF for the structures of various SOA length was performed (fig. 4). In the calculation, the DFB length was fixed to 300 μm, and a relatively high input signal power of 0 dBm was assumed. The figure shows that the structure only with an output-side SOA is more advantageous for NF characteristics. It is because that the signal amplification in the input-side SOA makes the gain saturation in output-side SOA more emphasized.

4 Summary

We systematically measured the NF of an SOA integrated DFB laser as a NDFWM wavelength converter. Law ASE noise due to the gain saturation by in-line pump wave, makes the NF relatively small. The achieved NF of 24 dB at 1 THz detuning was almost equivalent to the best result reported by FWM in much longer SOA device. The simulation was performed using the parameters obtained by the systematic NF measurement, and it revealed that a longer output-side SOA gives better NF characteristics.

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