IMPACTS OF PUMP MODULATION ON GAIN AND NOISE OF DISTRIBUTED RAMAN AMPLIFIER

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Abstract

Effects of pump modulation technique of two-pump wavelength Raman fiber amplifier were presented. The pump wavelength modulation was achieved using pulsed-drive current from the laser diode controller. The selection of modulation frequency was critical in this pumping technique which created temporal gain variations. The maximum temporal gain variation of 0.45 dB was recorded at 10 kHz modulation frequency while this factor was eliminated at higher frequencies; 300 kHz. The effective noise figure also degraded when utilizing this pumping scheme due to the arising of amplified spontaneous emission.

Keywords: Raman, optical amplifiers, pump modulation, optical communications, wavelength division multiplexing

Introduction

In recent years, multi-wavelength pumped Raman amplifiers have attracted more attentions due to their flat and seamless gain bandwidth (Emori *et al.*, 1999). The main problem of implementing this technology is the effect of nonlinear pump-to-pump interaction (Kidorf *et al.*, 1999). Therefore, a new technique of time division multiplexing (TDM) of pump wavelengths for Raman fiber amplifier was introduced to eliminate these problems and furthermore, an efficient way of improving noise performance (Mollenauer *et al.*, 2002). There are two techniques of which to achieve TDM of pump wavelengths. In the first technique, a single laser is driven constantly and the pump wavelength is swept in a specific pattern namely as pump-wavelength scanning (Mollenauer *et al.*, 2002; Winzer *et al.*, 2002a). This approach can produce the desired flat-gain region and only limited by the wavelength tuning capability of the pump laser. The second technique utilizes optical multiplexing of a number of fixed pump wavelengths (Fludger *et al.*, 2002). The pump wavelengths can be selected to appear at separate times by using pulsed drive currents. The pulse modulation rate used in the report was 1 MHz. However, the pulse modulation technique can also introduce the effect of temporal gain (Winzer *et al.*, 2002b). In this case, the modulation rate cause gain variation at frequencies below its

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threshold however, the impact of this technique on noise was not discussed.

This paper discusses the impacts of pump modulation using only two-pump wavelength in a counter-pumped distributed Raman amplifier. The experimental results show that the gain variation caused by slow modulation frequency and at the same time, noise is degraded comparing to the traditional pumping scheme.

Materials and Methods

The configuration of two-pump wavelength Raman fiber amplifier is shown in Figure 1. The pump wavelengths used in the experiment are 1,436 and 1,456 nm. Each pump wavelength is built from two semiconductor lasers that multiplexed via polarization beam combiner to minimize the effect of polarization dependent of Raman gain. All the semiconductor lasers are connected to laser diode controllers (LDC). The laser diode controller has the capability of internal modulation by a square wave up to 300 kHz. Pump combiner is used to multiplex these pump wavelengths and finally, a circulator is implemented as pump and signal multiplexer. The amplifying medium used in the experiment is 80 km standard single mode fiber, SMF-28. The attenuation coefficient is around 0.21 dB/km in the 1,550 nm window. The WDM source comprises of 44 discrete channels from 1,528.78 to 1,563.05 nm with 0.8 nm spacing. The input signal power is fixed to 14 dBm at the input of the single mode fiber. The output signal from the circulator is fed into the optical spectrum analyzer for measuring the peak signal levels and the noise floor. The measurement of on-off Raman gain is performed automatically using automatic data acquisition that is sampled at 1 MHz. From these measurements, the on-off gain ($G_{on\text{-}off}$) can be calculated using the following equation:

$$G_{on-off} = \frac{P_{out}^{on}}{P_{out}^{off}}, \tag{1}$$

where P_{out}^{on} and P_{out}^{off} are the output power when the Raman pump is turned on and off respectively. The effective noise (N_{eff}) can be calculated using the following derivation:

$$N_{eff} = \frac{\rho_{ase}}{G_{on-off} h\nu\Delta\nu} \tag{2}$$

where ρ_{ase} is the ASE power density, h is the Planck constant, ν is the signal frequency and $\Delta\nu$ is the resolution bandwidth.

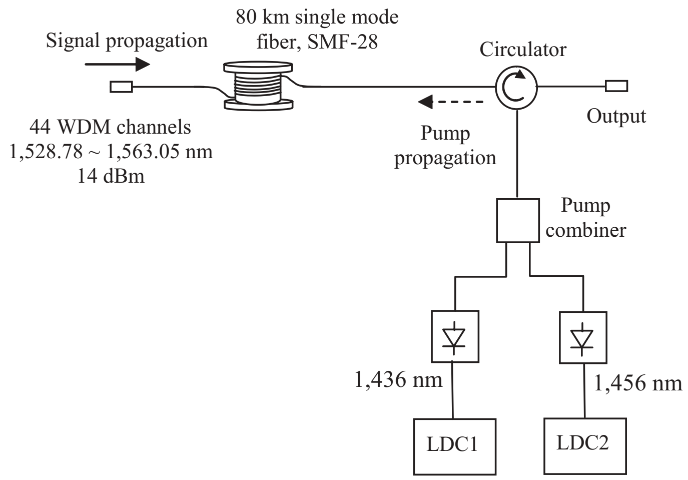

Figure 1. The experimental configuration of time division multiplexing of two pump wavelengths in a counter-pumped distributed Raman amplifier.

Time-division multiplexing of pump wavelengths can be achieved by controlling the laser driving currents from the laser diode controller as depicted in Figure 2. This utilizes the built-in function of the laser diode controller. The waveform of the modulated current is a square wave and 50% duty cycle. The cycle time of the pump modulation technique is shown in Figure 2. In this experiment, the phase of the modulated laser current cannot be controlled, therefore only one pump wavelength can be modulated and the other pump wavelength is fixed constantly throughout the experiment (dashed line). Two sets of pump wavelength TDM are used namely as TDM1 (1,436 nm is modulated and 1,456 nm is fixed) and TDM2 (1,436 nm is fixed and 1,456 nm is modulated). Based on the modulation scheme used in the experiment, the average pump power of the modulated pump wavelength drops to 50% of its maximum. Therefore in order to sustain the original condition whereby the total power is the same, the modulated pump power must be increased twice from its original value.

Results and Discussions

Basic characterizations of Raman fiber amplifier using continuous wave (CW) are depicted in Figure 3. The pump powers from the Raman pump lasers are adjusted to obtain on-off Raman gain at 5 dB only. The best pump power combination of this two-pump wavelength Raman amplifier system that produces gain variation of less than 1 dB is selected and recorded. The pump powers are 75 and 118 mW

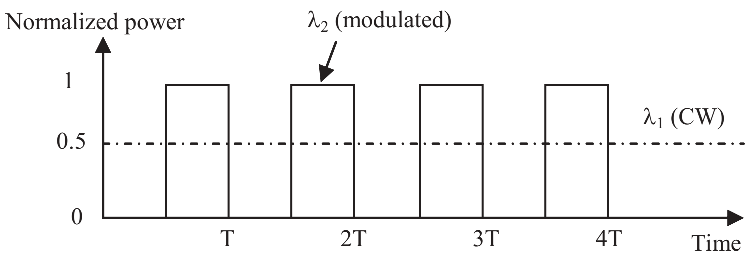

Figure 2. Pump modulation scheme of 2-pump wavelength Raman amplifier.

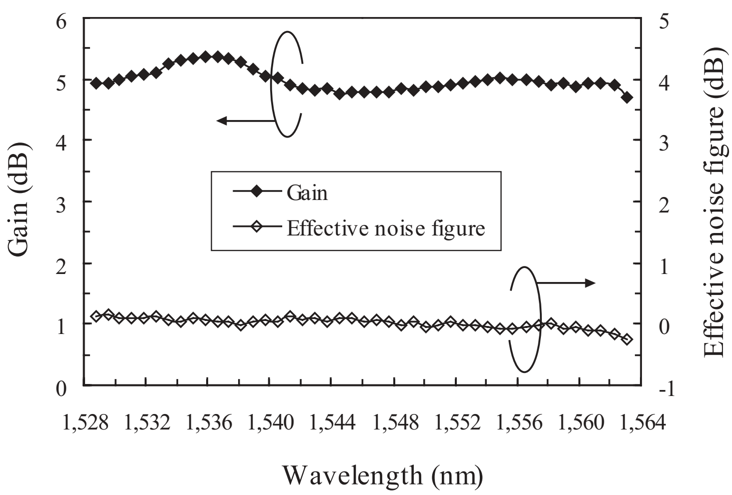

Figure 3. Gain and effective noise figure of Raman amplifier pumped by CW laser diodes.

for 1,436 and 1,456 nm respectively. These measurements are set as the reference ones to evaluate the impacts of pump modulation.

The effect of frequency modulation is studied using the condition of TDM1, the pump powers are 150 and 118 mW for 1,436 and 1,456 nm respectively. Two sets of frequency are used in the experiment; 10 and 300 kHz. The on-off Raman gain and effective noise figure are measured using this modulation scheme. Then, the gain discrepancy between the measured data and the reference set for CW pumping scheme is depicted in Figure 4. Referring to the graph, it is clear that the gain variation is worse at low modulation frequency and the maximum gain variation of 0.45 dB is recorded in the experiment with the mean value of 0.18 dB. These show that the on-off Raman gain at 10 kHz modulation frequency has temporal gain variations that caused by fast Raman gain response in the fiber. However, this effect vanishes as the modulation frequency increases to 300 kHz; the mean gain variation is almost negligible of less than 0.01 dB. Even though that the gain variation here does not present the absolute value, it relatively shows the presence of temporal effect at low modulation frequencies. Based on the findings, the selection of pump modulation frequency should be considered in the distributed Raman amplifier design even though only single pump laser is modulated.

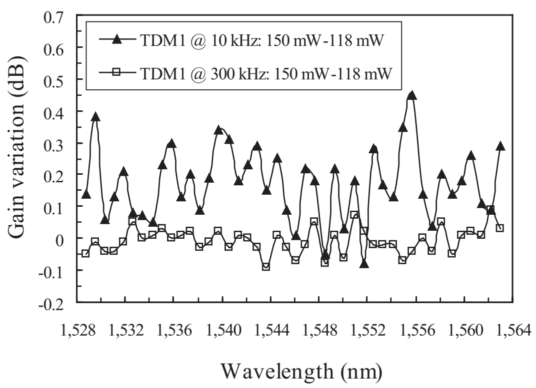

Figure 4. Gain variation with respect to CW on-off Raman gain at different modulation frequencies; 10 and 300 kHz.

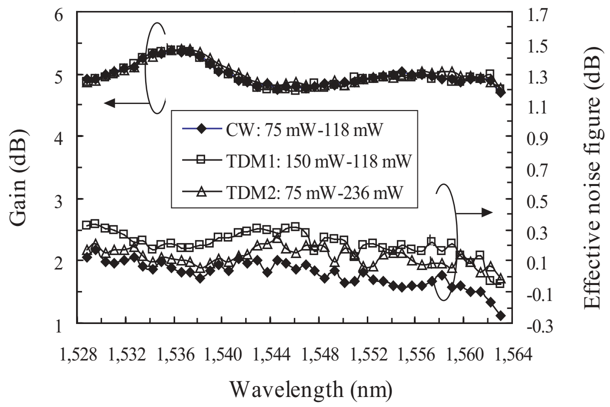

Figure 5. Gain and effective noise figure against wavelength with CW pump wavelength and modulated pump wavelength at 300 kHz.

In this experiment, only single pump laser can be modulated at one time because the phase of the modulated drive-current cannot be controlled. Therefore, another experiment is performed to investigate the effect of the current modulation on the selection of pump wavelength. In this case, the combination of pump wavelengths as described earlier in this paper. The experimental results of on-off Raman gain and effective noise figure are shown in Figure 5. It can be seen that the on-off Raman gain is almost the same regardless of the type of pumping scheme used in the experiment. However, the effective noise figure portrays a slightly different behavior for all the pumping schemes. The effective noise figure of the CW pumping scheme has the lowest value and is set as the reference set. The pumping scheme of TDM1 produces the worst effective noise figure amongst all the three pumping schemes. The deterioration of the effective noise figure for both pump modulation schemes could be due to the impact of the arising of amplified spontaneous emission levels at the output of the distributed Raman amplifier (Bromage *et al.*, 2003). This problem was experimentally observed when the instantaneous pump powers were too high in the pump-wavelength scanning technique. This could be due to the imperfection of the laser diode controller while producing pulses that can create a large transient in the pump power.

Conclusions

The effects of pump modulation technique incorporating two-pump wavelength Raman fiber amplifier have been discussed. The experimental results show that the modulation frequency of the drive current plays important role to minimize the effect of temporal gain variations in this type of pumping scheme. The value of temporal gain variation as high as 0.45 dB is measured at 10 kHz modulation frequency. Beside this, the modulation of the drive current can also introduce some degrees of effective noise figure deterioration due to the arising of amplified spontaneous emission. This problem is experimentally observed even though only two pump lasers are used in the study. These problems should be considered in designing distributed Raman amplifiers using pump-wavelength modulation.

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