Dispersion Compensating Raman Amplifier for the L-Band

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ABSTRACT

We present a dispersion compensating fiber Raman amplifier for the L-band, obtained by pumping a dispersion compensating fiber with a high power 1480 nm Raman pump. The device described here is useful for the upgrade of DWDM transmission systems, considering that increasing the transmission bit rate requires extra power budget and dispersion compensation. The dispersion compensating Raman amplifier was tested in two configurations, backward and forward pumping. A net gain of 13 dB is obtained at 1580 nm for 600 mW of 1480 nm backward pump power. The on-off gain in this condition is 27 dB.

1. INTRODUCTION

The upgrade of installed DWDM transmission systems by increasing the bit rate requires attention to tighter power budget and dispersion limitations. Higher bit rate pulses are more susceptible to fiber dispersion and dispersion compensators are required when implementing the upgrade. Dispersion compensating fibers (DCF) are usually deployed to compensate for fiber dispersion. DCFs present high loss (~0.5 dB/km @ 1550 nm), imposing power budget limitations for the bit rate upgrade. It has been demonstrated recently that the dispersion compensating unit loss can be compensated by using Raman amplification in the DCF. [1] This fiber has a very small effective area (~25 μm^2), providing the highest Raman gain among all fiber types.[2],[3]

There is another impact on the power budget which is given by the fact that the receiver sensitivity to obtain a given bit error rate is worse for higher bit rates. In a transmission system the amplifiers and fiber links are designed for a given bit rate. In order to upgrade the bit rate, it would be necessary to provide extra gain to compensate for the change in receiver sensitivity. Raman gain in DCF modules can be high enough to compensate for its loss and for the extra power necessary to the upgrade. [4]-[7]

The limitations described here become more critical in the L-band (1560-1610 nm), where the fiber loss and dispersion are higher than in the C band (1530-1560 nm). It has been shown that the higher fiber loss in the L-band can be compensated by pumping the transmission fiber at 1530 nm to obtain distributed Raman gain. [9]

We present here an element which provides both power and dispersion compensation to be used in DWDM system upgrades in the L-band. This element is obtained by pumping a DCF with a 1480-nm Raman pump. The net gain and the noise figure were measured in the L-band for various pump and signal powers.

2. EXPERIMENTAL SETUP

The experimental setups are shown in Figure 1. The Raman amplifier is pumped by a cascaded Raman laser, which is a double-clad fiber laser pumped by an array of multi-mode pump modules, followed by a cascade of fixed resonators.

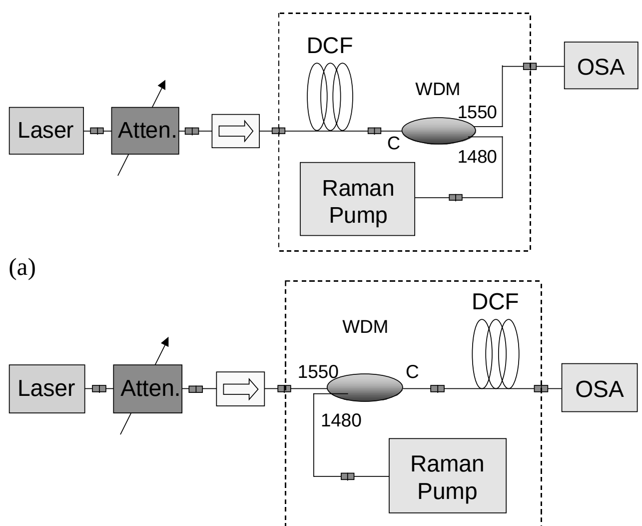

Figure 1. Experimental setup. The dispersion compensating L-band Raman amplifier is pumped by a Raman laser. (a) Backward pump configuration, (b) Forward pump configuration.

The pump light is coupled into the transmission fiber using a 1480/1550 nm WDM coupler, designed for high pump powers. The pump wavelength is 1480 nm and the signal, generated by a tunable external cavity laser, is tuned from 1560 to 1600 nm, covering most of the L-band.

The net gain and the Raman noise are measured using an OSA, coupled to the transmission fiber output by the coupler 1550 nm port in the backward configuration and directly to the transmission fiber in the forward configuration. For both configurations, the input signal power considered is the power exiting the isolator, e.g. the dispersion compensating Raman amplifier includes both the DCF and the WDM coupler.

The DCF used as Raman gain medium has a total dispersion of –1600 ps/nm and it is composed by two DCFs connected, one of –700 ps/nm and one of –900 ps/nm. Total insertion loss of both DCFs connected is 12.0 dB at 1550 nm. All the connectors used are angled polished connectors to reduce reflections, which might cause oscillations.

3. RESULTS AND DISCUSSION

Distributed Raman amplifiers are characterized by the on-off gain, which is the ratio between the output signal power with the pumps on and off. In this case, the important parameter is the net gain, because this is a discrete amplifier and it can be used to compensate for losses other than the DCF insertion loss. The net gain is given by the ratio between the output signal power and the input signal power.

The noise figure for Raman amplifiers is calculated by taking into account the net gain and the measured noise power.

3.1 Backward Pump Configuration

Figure 2 shows the DCF Raman amplifier net gain and the noise figure, in dB, as a function of the signal wavelength. This is the result for the backward pump configuration and the curves shown correspond to two pump power levels, 500 and 600 mW.

Although backward pump configuration has been shown to minimize the effect of pump fluctuations on the amplifier gain, [10] the dispersion compensating Raman amplifier has been characterized for forward pump configuration also, so that the pump power limits could be obtained in this condition.

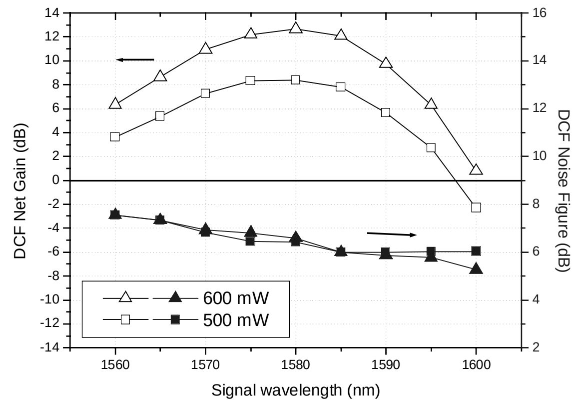

Figure 2. Net gain and noise figure for the dispersion compensating Raman amplifier, backward pumped at 1480 nm as a function of the signal wavelength. The signal power level is –13 dBm.

Considering that we are describing a discrete amplifier, the net gain takes into account the loss of the DCF and of the WDM coupler. The loss of the DCF varies less than 1 dB over the wavelength range covered by the measurements (1560 to 1600 nm). The WDM coupler is optimized for the wavelength range near 1550 nm and it has high insertion loss towards the long wavelength side. For 1600 nm, the insertion loss is as high as 7 dB. Figure 3 shows the insertion loss of the DCF and the WDM coupler.

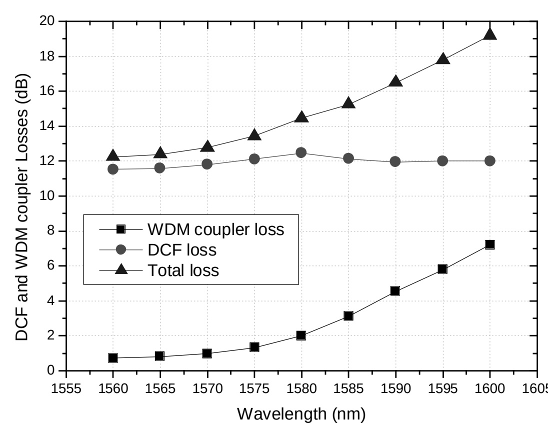

Figure 3. DCF and WDM coupler insertion loss, as a function of wavelength.

The net gain variation is 12 dB and can be reduced by using a WDM coupler optimized for the L band, which requires a lower and flatter insertion loss towards the longer wavelength side.

For pump powers above 670 mW, the amplifier starts to oscillate due to Rayleigh scattering. [11] We observed also that the threshold for oscillation depends on the length and on the sequence of the DCFs used. Table 1 shows the oscillation thresholds for four combinations of the available DCFs. Longer fiber lengths have higher gain and consequently lower threshold. The connection between the DCFs also causes reduction of the threshold, due to extra reflections. These oscillations due to Rayleigh scattering can be reduced by using band pass filters [12] and gain flattening filters. [13] In the configurations tested here, none of these techniques was used and for this reason, the pump power level was kept under 670 mW.

Table 1 – Oscillation pump power thresholds for DCFs.

DCF (ps/nm)	Pump power threshold (mW)
-700	800
-700 / -900	730
-900	710
-900 / -700	670

Figures 4 and 5 show the net gain and the noise figure of the dispersion compensating Raman amplifier as a function of the pump power.

In order to compensate for the DCF loss, it is necessary to pump the DCF with a power of at least 300 to 400 mW, depending on the signal wavelength. For pump powers in this range, the dispersion is compensated by a lossless device. For pump powers above this power range, this device can be used to compensate for both dispersion and extra losses associated to the system upgrade.

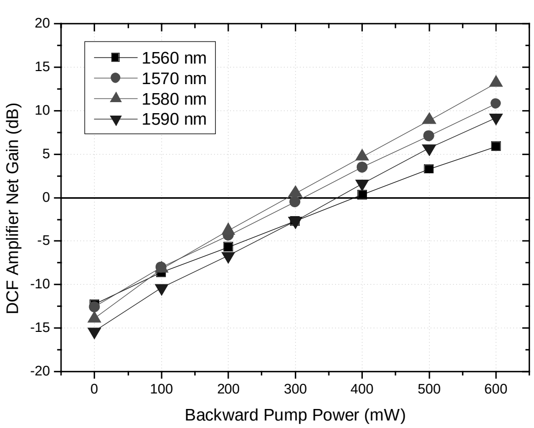

Figure 4. Net gain for the dispersion compensating Raman amplifier, backward pumped at 1480 nm as a function of the pump power. The signal power level at the input of the DCF is –13 dBm.

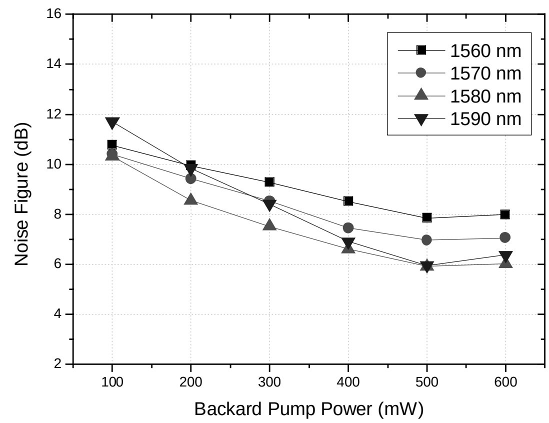

Figure 5. Noise figure for the dispersion compensating Raman amplifier, backward pumped at 1480 nm as a function of the pump power. The signal power level at the input of the DCF is –13 dBm.

Figure 6 shows the net Raman gain as a function of the signal wavelength for five different signal input power levels. The pump power is 400 mW. The reason to use this pump power level is to compare with the forward configuration as it will be explained in section 3.2.

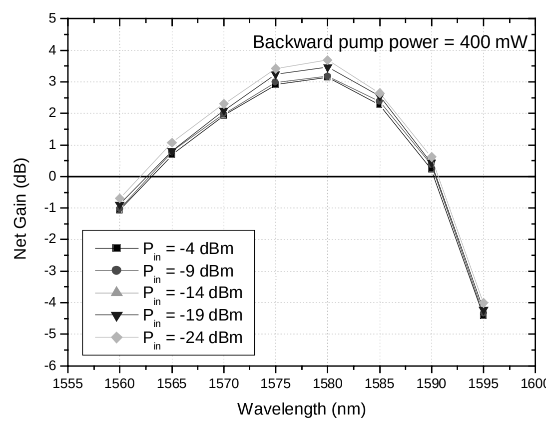

Figure 6. Net gain for the dispersion compensating Raman amplifier, backward pumped at 1480 nm as a function of the signal wavelength, for five different signal power levels.

As expected, the dispersion compensating Raman amplifier gain is signal independent for the power range measured.

3.2 Forward Pump Configuration

Figure 7 shows the DCF Raman amplifier net gain and the noise figure, in dB, as a function of the signal wavelength. This is the result for the forward pump configuration and the curves shown correspond to two pump power levels, 500 and 600 mW.

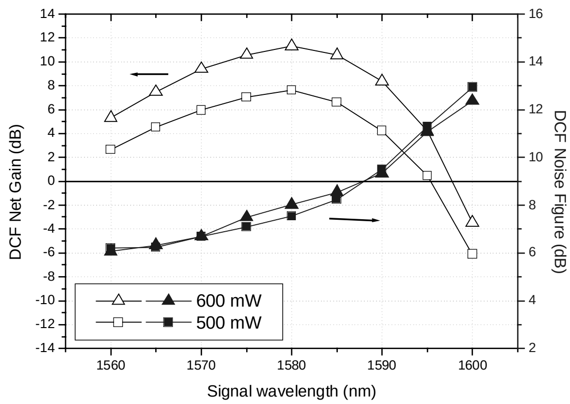

Figure 7 . Net gain and noise figure for the dispersion compensating Raman amplifier, forward pumped at 1480 nm as a function of the signal wavelength. The signal power level is –13 dBm.

The forward pump configuration provides lower gain the backward pump configuration. The difference ranges from 1 to 4 dB and it increases for longer wavelengths.

The main difference is in the noise figure, which for the forward pump configuration is higher than for the backward pump, specially for longer wavelengths. The largest noise figure difference observed is 7 dB for 1600 nm. This difference comes from the fact that in the forward configuration, the signal is attenuated by the WDM coupler in the long wavelength range, but the noise is not attenuated, since the OSA is directly connected to the Raman gain medium. In the backward configuration both the signal and the noise are attenuated by the WDM coupler and noise figure is not affected by this loss.

Figures 8 and 9 show the net gain and the noise figure of the dispersion compensating Raman amplifier as a function of the pump power.

The pump power range to compensate for the DCF loss, is approximately the same as for the backward pump configuration, 300 to 400 mW, depending on the signal wavelength.

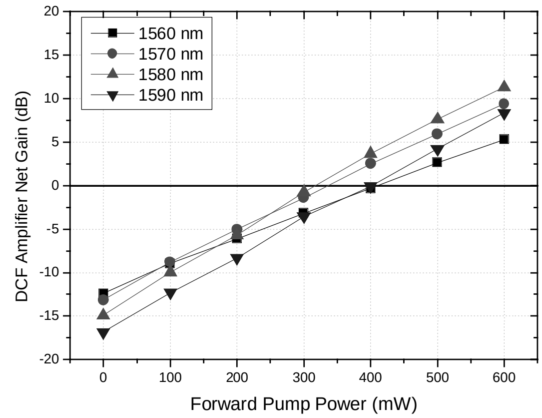

Figure 8. Net gain for the dispersion compensating Raman amplifier, forward pumped at 1480 nm as a function of the pump power. The signal power level at the input of the DCF is –13 dBm.

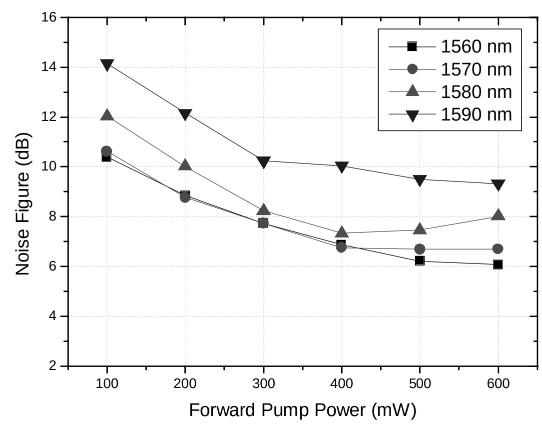

Figure 9. Noise figure for forward pumped at 1480 nm as a function of the pump power. The signal power level at the input of the DCF is –13 dBm.

Figure 10 shows the net Raman gain as a function of the signal wavelength for four different signal input power levels. The pump power is 400 mW. We could not use higher pump power levels, because gain fluctuations are observed, specially for high signal level. [10] This result indicates the limit of pump power that can be used in order to keep the gain fluctuation low. In this condition, the maximum net gain from the forward pump configuration is 3dB.

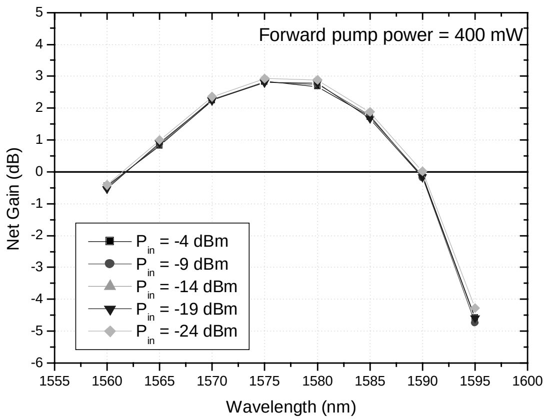

Figure 10. Net gain for the dispersion compensating Raman amplifier, forward pumped at 1480 nm as a function of the signal wavelength, for five different signal power levels.

As expected, the dispersion compensating Raman amplifier gain is signal independent for the power range measured.

4. CONCLUSION

We presented a dispersion compensating L-band Raman amplifier which can be used to compensate for dispersion and loss simultaneously. This device should prove useful for systems upgrades and to extend the wavelength band of the erbium doped amplifier.

The highest net gain measured for the backward pump configuration is 13 dB, for 600 mW of backward pump power. The noise figure in this configuration is below 7.5 dB. For the forward pump configuration, the highest net gain is 3 dB and it is limited by the gain fluctuations induced by the pump.

5. REFERENCES

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