

Influences on gain performance of discrete fiber Raman amplifier

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The effects on gain level and gain flatness of discrete Raman fiber amplifier are investigated both theoretically and experimentally. Gain level is related to pump configuration and signal power in certain pump power and fiber length. Gain flatness depends on gain level and signal power. A numerical model has been used for the theoretical analysis. The optimization algorithm for gain-flattened amplifier also has been used for the gain flatness analysis. In a conclusion, if the pump power increases to obtain high net gain level in large signal power case, the good gain flatness should be obtained through changing pump wavelength and pump number in the case.

(Received December 21, 2006; accepted January 15, 2007)

Keywords: Raman amplifier, Gain flatness, Saturation, Optical fiber communication

1. Introduction

With the increase of the communication network and Internet capacity, fibre Raman amplifiers have recently been recognized as one of the key technologies to realize the all-optical amplification in the broad-band dense wavelength-division-multiplexing systems due to their distinctive broadband gain and low noise. The broadband gain can be obtained if multiple pumps are employed, and the gain profile can be flattened if the pump configuration is appropriately designed.

The gain property is the key performance of the broadband fibre Raman amplifier. Many studies on gain characteristics are taken [1-3]. The experiment study and theory analysis on gain property should be taken to optimal the performance of amplifier. In this paper, we take some experiments about the gain property including the gain level and the gain flatness. The theory analysis is also taken in order to obtain the qualitative behaviour of the gain property. Then, some advices are proposed to optimize the gain property.

2. Experimentation

A schematic diagram of our experimental setup is shown in Fig. 1. A pump module consists of six laser diode sources with four wavelengths, several couplers and fiber depolarizers. Six lights from pump module are coupled into the gain medium by the broadband fiber coupler. The pump configuration includes forward pumping and backward pumping according to the direction relation between the pump light and signal light. Fig. 1 (a) (b) denotes the forward pumping configuration and the backward pumping configuration, respectively. The broadband discrete fiber Raman amplifier consists of the 8.5 km dispersion compensation fiber (DCF) and pump module. The signal source is the broadband source (BBS). The optical isolation placed in front of the signal source prevents counter-propagation of light from impacting signal light.

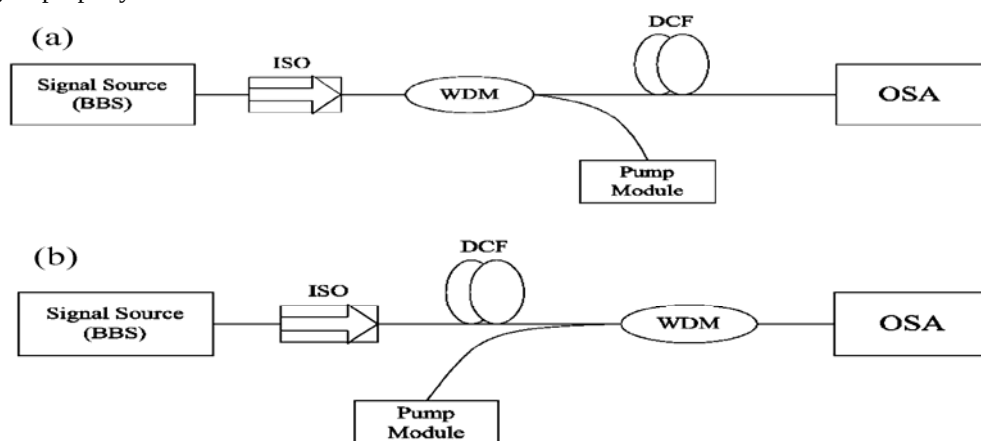


Fig.1. The schematic diagram of experiment setup (a) forward pump (b) backward pump.

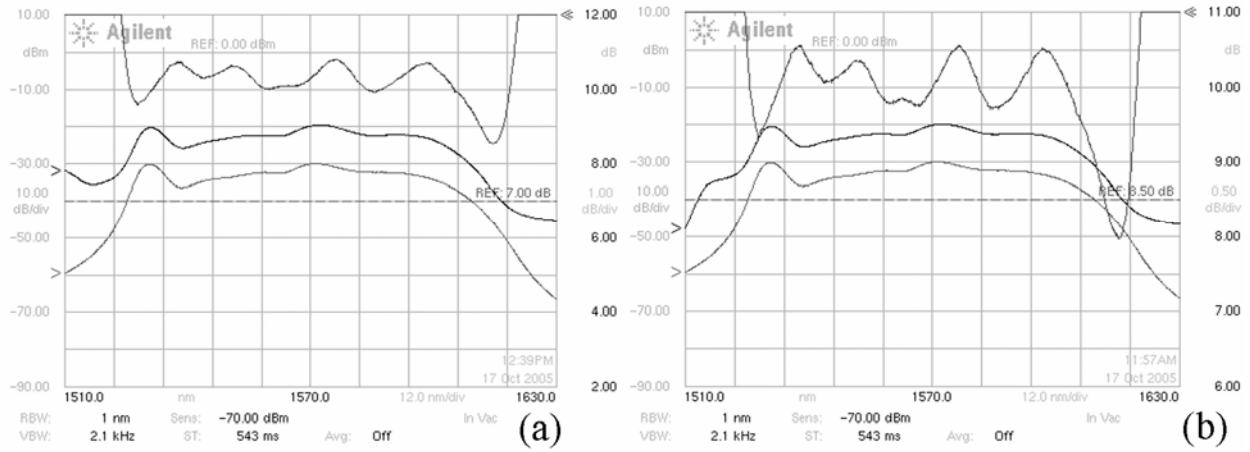


Fig. 2. The net gain profiles about 5dB level in forward and backward pump.

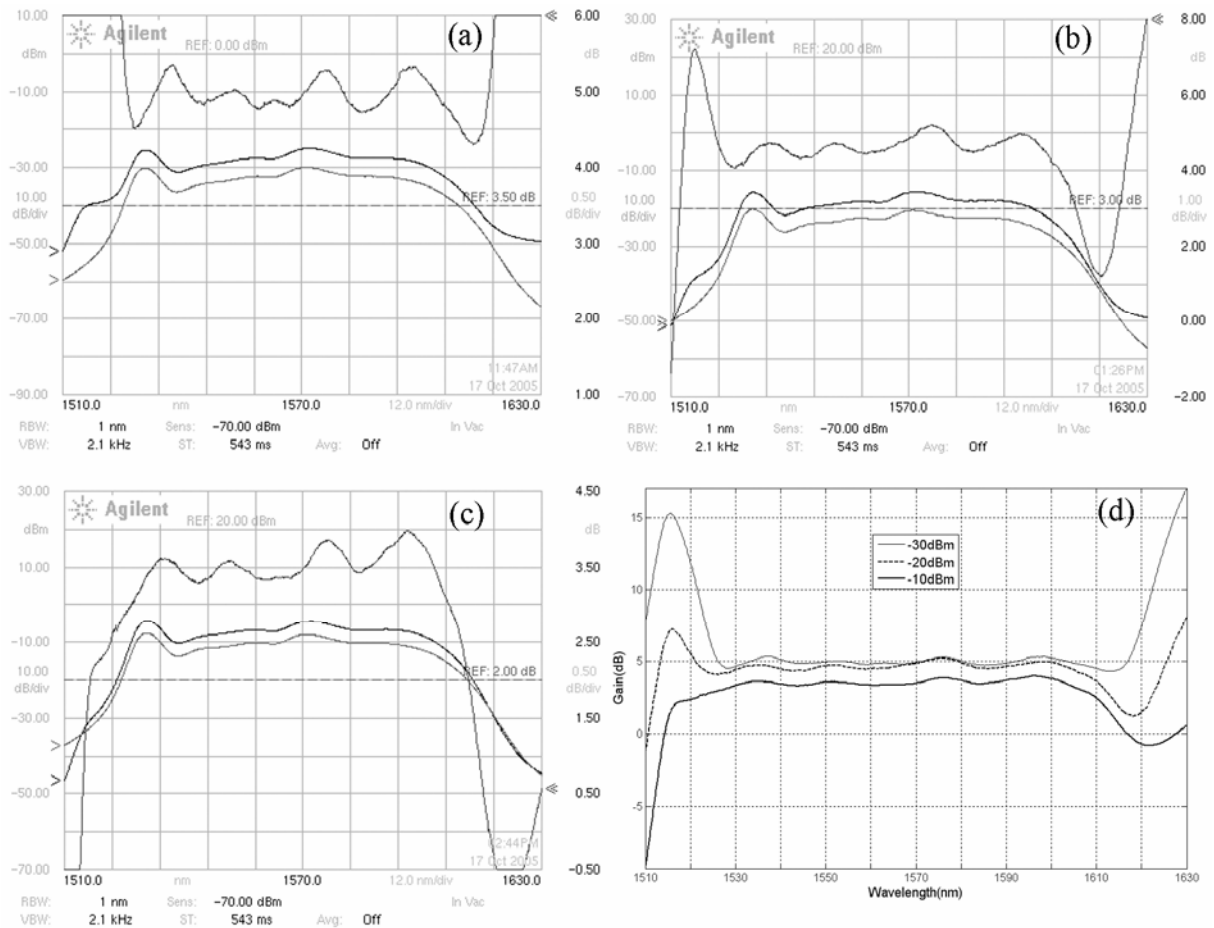


Fig. 3. The net gain profiles with three signal levels in the same pump power and backward pump.

The pump configuration dependence of gain level was measured by using two pumping configurations in same pump power scheme. Fig. 2 shows the input, output signal lights and the net gain in different pumping configuration with the signal power density -30dB/nm .

From the figure, we can see that the gain levels are almost the same with different pumping configuration in the small signal case. However, gain flatness is different in this signal case because of the difference of pump configuration.

The signal power dependence of gain level was measured by using three signal powers in same pump power and pump configuration. Fig. 3 shows the net gain against the input signal power in the backward pumping configuration. The comparison about three net gains is demonstrated in Fig. 3 (d). With increasing input signal power density, the gain level of backward-pumping amplifier is decreasing.

The gain saturation characteristic of the amplifier was exhibited in Fig. 3(d). In the certain pump power, the gain level of the amplifier drops along the increase of the input signal power.

The characteristic of gain level related to pump configuration and signal power was investigated. In the following paragraph, we present the characteristic of gain flatness related gain level and signal power.

The gain level dependence of gain flatness was measured by obtaining the optimal gain flatness in

different gain level through adjusting pump power scheme manually. Gain flatness is dependent on gain level in certain signal power and pump configuration. Fig. 4 demonstrates gain flatness for four gain levels in same signal power density -20dBm/nm and backward pumping configuration. It can be seen that the optimal gain flatness increase along the increase of gain level.

The signal power dependence of gain flatness was measured by using various signal powers in certain gain level. In certain gain level 10dB , gain flatness with various signal power density in backward pump configuration is shown in Fig. 5. Then, the comparison of gain flatness is plotted in Fig. 5(d). From the figure, we can see that gain flatness is largest in the case of signal power density -20dBm/nm because of the higher gain level than others. In general, gain flatness would increase with the increase of signal power density. The detailed analysis is mentioned in the following section.

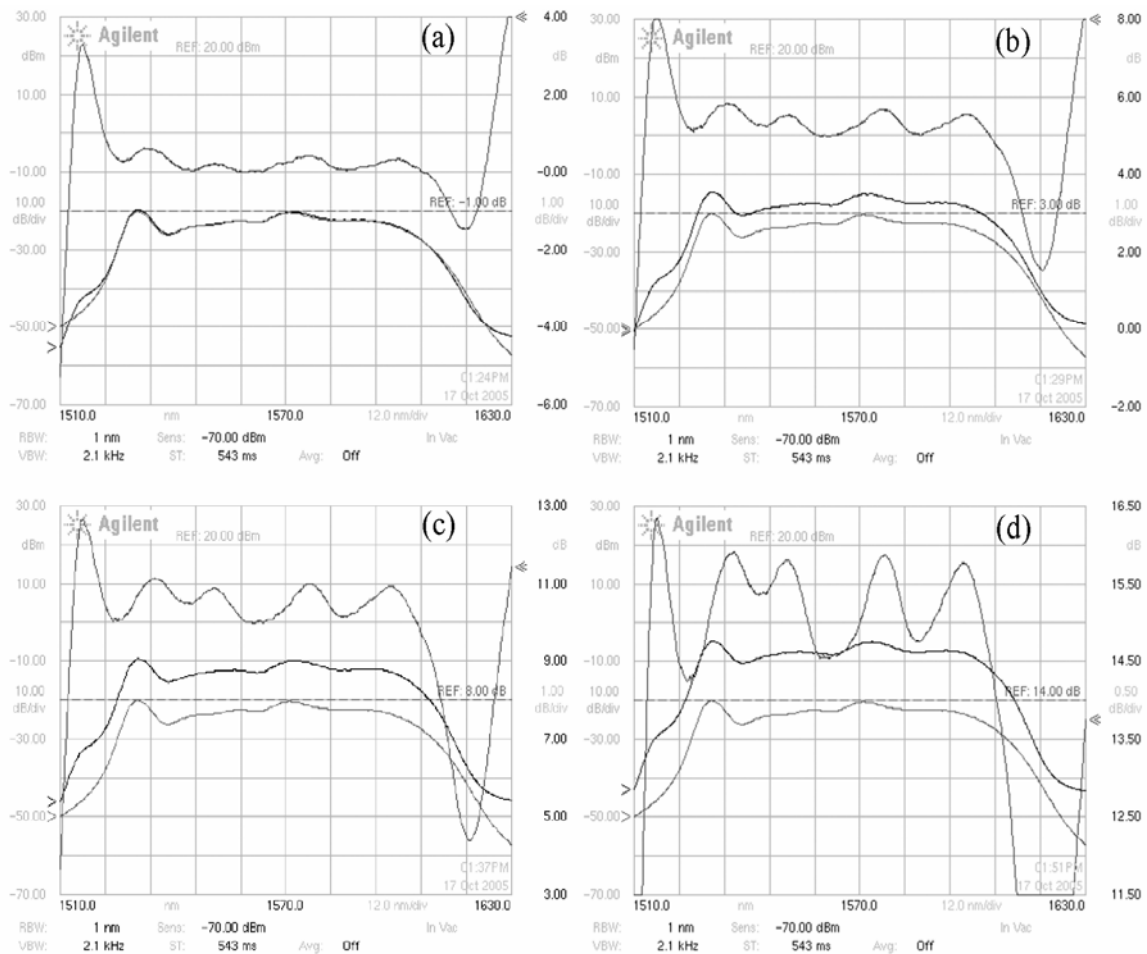


Fig. 4. Gain flatness in various gain level with the signal density -20dBm/nm and backward pump configuration.

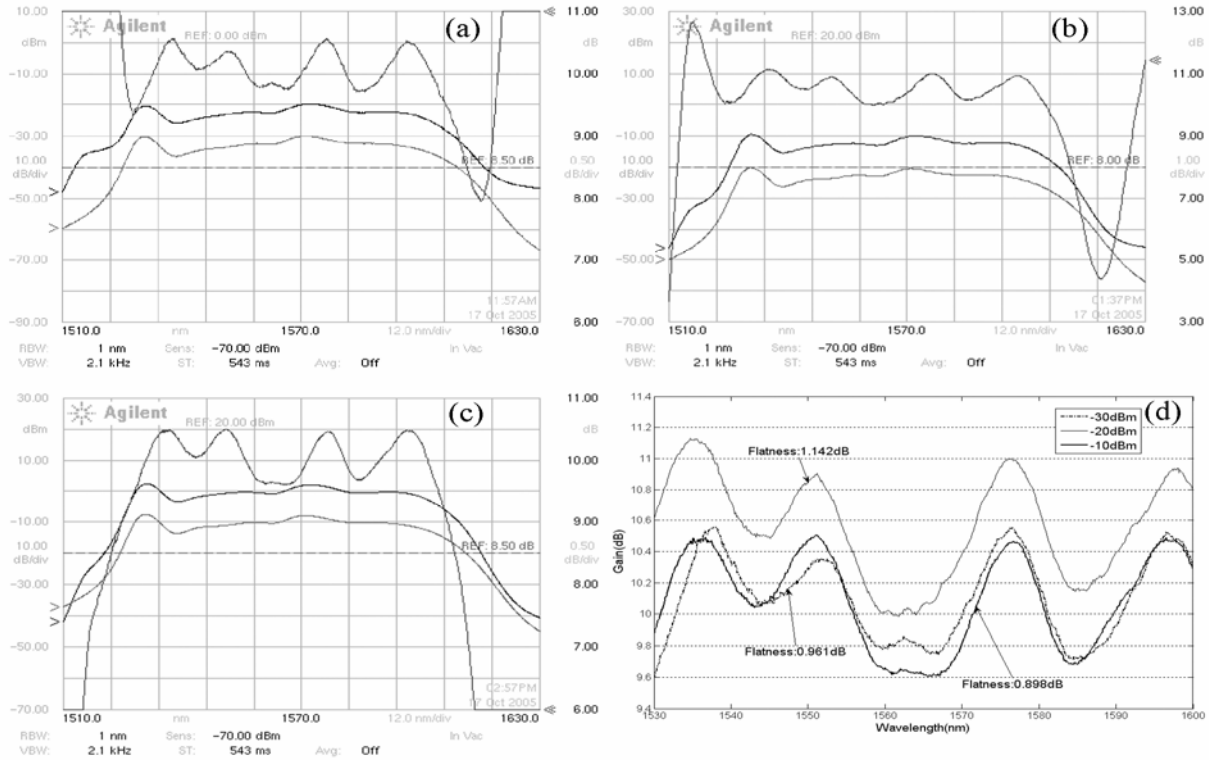


Fig. 5. Gain flatness with various signal power density in certain gain level and backward pump configuration.

3. Theory analysis

In the steady state, the coupled equation in the multi-wavelength pumped Raman amplifier can be described as [4]:

$$\frac{d}{dz}P_i(z) = \pm P_i(z) \left[-\alpha_i + \sum_{j=1}^{i-1} g_{ij} \frac{P_j(z)}{K_{ij}A_{ij}} - \sum_{j=i+1}^N g_{ij} \frac{\lambda_j}{\lambda_i} \frac{P_j(z)}{K_{ij}A_{ij}} \right], 1 \leq i \leq N$$

Here, the value $P_i(z)$, λ_i and α_i describe, respectively, the power, wavelength, and the linear attenuation coefficient for the i th wave. g_{ij} is the Raman gain coefficient in the fibre between waves i and j , A_{ij} is the effective area of the fibre, and K_{ij} is a polarization factor. N is the total number of pumps and signal channels. The sign $\pm$ denotes the direction of propagation. This model does not take into consideration spontaneous Raman scattering and Rayleigh backscattering, because these noise do not affect the amplifier gain profile.

In our simulations, the amplifier has two pump configuration including counter-directional pumping and co-direction pumping. The Raman gain coefficient, the linear attenuation and the length of DCF in the experiment are used in the numerical simulation. The pump wavelengths and powers are also utilised. The density multi-wavelength division systems with interval 100GHz is used to replace the broadband light source in the experiment in our simulation.

The pump configuration dependence of gain level was calculated in different signal power density. The result is shown in Fig. 6 for signal power density equal to -20 and -10 dBm/channel. Gain profiles are almost same in small signal power. However, they have distinct difference in large signal power. Gain profile of backward pumping leans to long wavelength, and it of forward pumping leans to short wavelength.

Fig. 7 demonstrates the signal power dependence of gain level of backward-pump Raman amplifier. Three gain curves express the gains in signal power density at -30, -20 and -10 dBm/channel, respectively. The lowest gain curve denotes the gain profile for signal power density equal to -10 dBm/channel. With the signal power increasing, the gain correspond to the signal power is descending.

The gain saturation of the amplifier is shown in Fig. 8. Based on Fig. 7, gain curves for higher signal power density at 0 and 5 dBm/channel are simulated. Fig. 8 (a) shows five gain curves for five signal power density. Fig. 8 (b) shows the gain level against input signal power from -30 to 5 dBm/channel, corresponding to Fig. 8 (a).

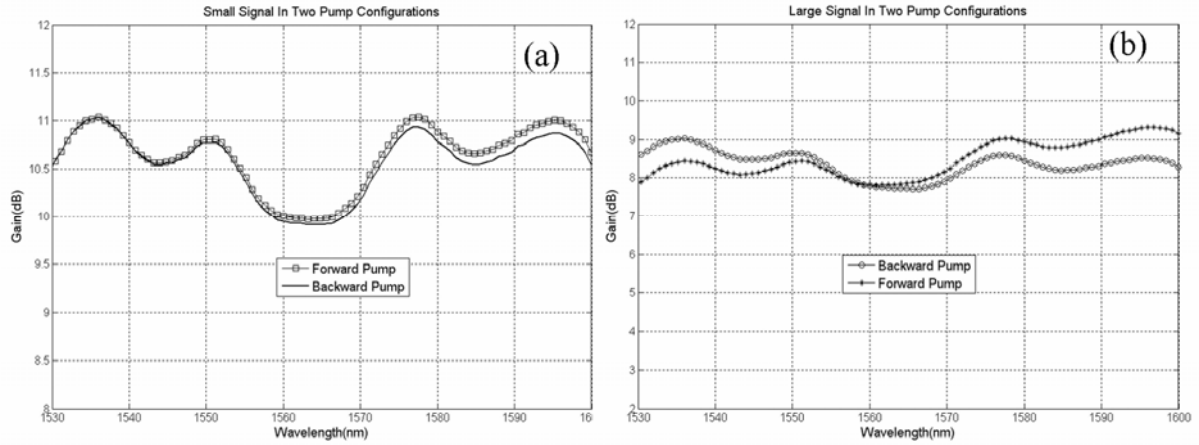


Fig. 6. Pump configuration dependence of gain level

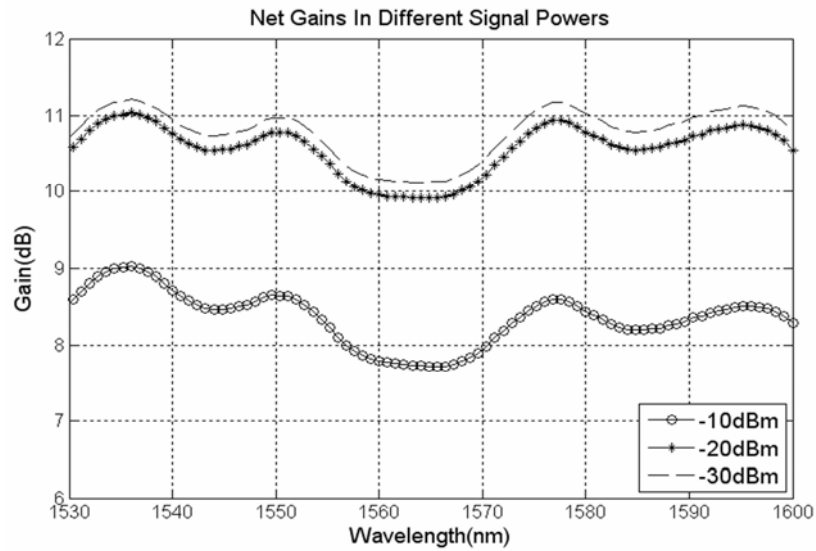


Fig. 7. Net gains in different signal powers

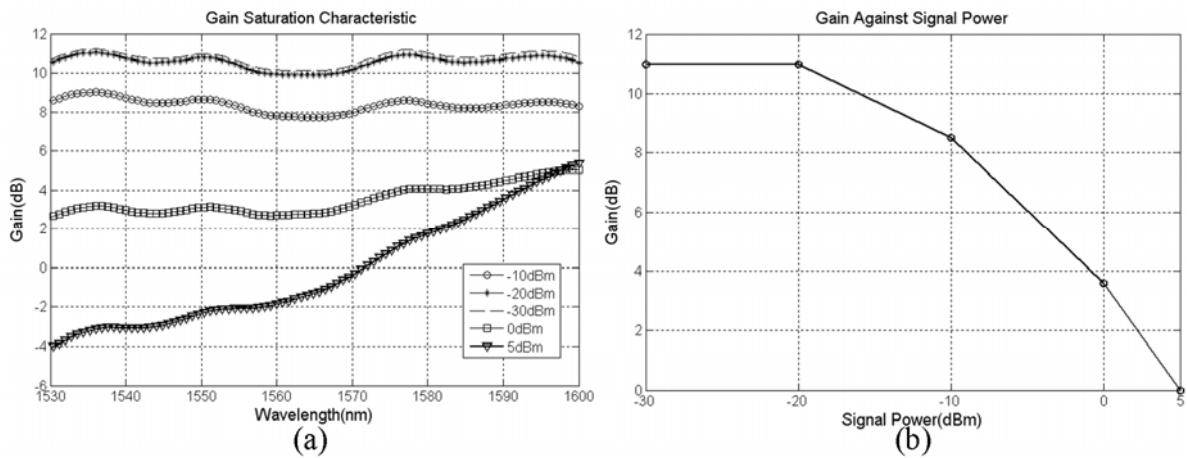


Fig. 8. Gain saturation characteristic of amplifier.

Gain level property is investigated above, next we will study gain flatness through numerical simulation

results. There are several factors that influence the gain flatness. They includes gain level, signal power, signal

band, pump wavelength configuration. In this paper, the influence of gain level and signal power are studied. The numerical stimulation results of optimal gain flatness are obtained through the proposed algorithm for gain flatness [5-7].

Fig. 9 shows the gain flatness of backward-pumping amplifier for the signal power density equal to -20dBm/channel for the gain levels 0dB, 5dB, 10dB, 15dB and 20dB. When the gain level increases, the gain flatness also increases. This is in qualitative agreement with the experimental results shown in Fig. 4.

The signal power dependence of gain flatness is calculated with a computer program. The results are shown in Fig. 10. In the figure, except the highest curves,

other three curves denote the optimal gain flatness for the gain level of 10 dB for the input signal power density equal to -30,-20 and -10 dBm/channel. It is concluded that the gain flatness decreases with the increase of signal power density in certain gain level and pump configuration. In the small signal case, the phenomenon that the gain flatness for -20 dBm /channel is smaller than that for -30 dBm/channel, results from the somewhat larger gain level for -30 dBm/channel. The case is also shown in Fig. 10. The highest curve in Fig. 10 is the gain profile for gain level of 10.4 dB with the optimal gain flatness. This flatness is larger than that for -10 dBm/channel, which is in agreement with the experimental results shown in Fig. 5.

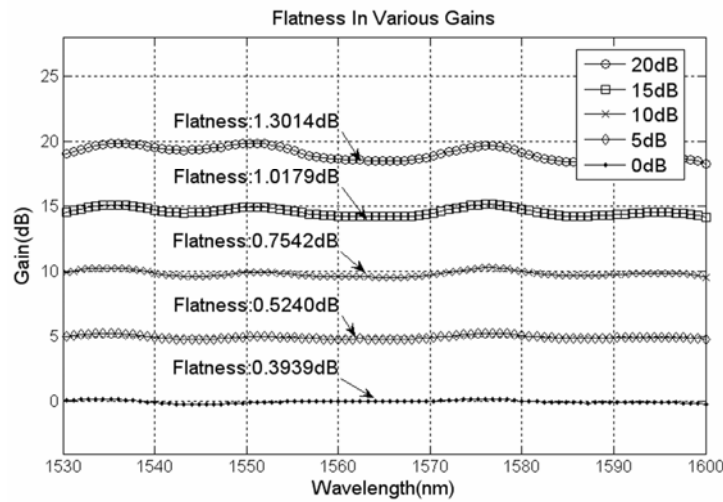


Fig. 9. Gain flatness in various gain levels

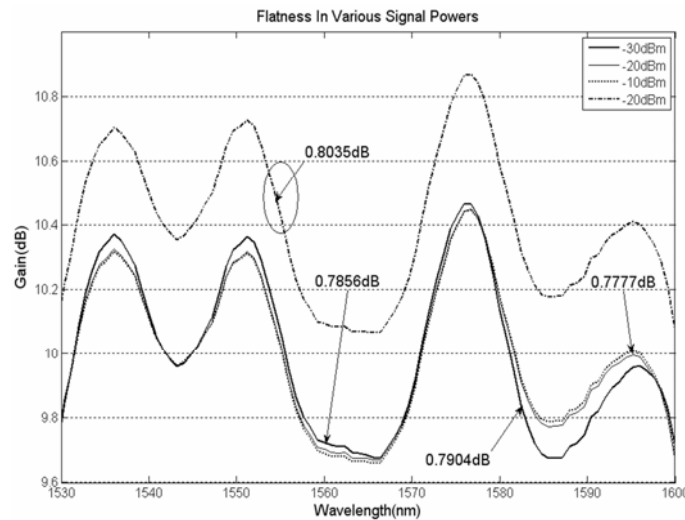


Fig. 10. Gain flatness in various signal powers.

4. Conclusions

We have carried out a detailed study of gain property in discrete Raman amplifier. Forward and backward pump configurations are used in Raman amplifier. Broadband light source in simulated DWDM systems is

utilized in the experiment in order to study the amplification band of Raman amplifier. The designed discrete Raman amplifier has 70 nm amplification band with 10 dB gain level and the optimal gain flatness below 1 dB. It is found that the gain level is almost not significant for two pump configuration in small signal

case. Even in large signal case only small difference in gain profile is obtained. The gain level is related directly to the signal power in certain pump power and fiber length case, which results in the saturation in Raman amplifier. Moreover, the gain flatness depends on gain level and signal power. The gain flatness goes worse with the increase of the two factors.

The theoretical analysis is based on the numerical model of Raman amplifier and the optimization algorithm for gain-flattened Raman amplifier. Qualitative agreement has been reached between experimental and theoretical results.

It is concluded that if the total pump power increases, in order to obtain high net gain in large signal power avoiding saturation, the good gain flatness should be got by changing pump wavelength and pump number.

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