Research of Gain and Bandwidth in Hybrid Fiber Raman Amplifier *

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Abstract Hybrid FRA consisting of general fiber G652 and dispersion compensation fiber DCF includes DCF + G652, G652 + DCF and G652 + DCF + G652. The operation principle is discussed. The optimum design of hybrid FRA has been done by using optimum design software of FRA--OptiAmplifier 4.0. The best structure is G652 + DCF. It can compensate dispersion and widen operation wavelength range of optical fiber network. Using Raman laser (1427 nm) as an exciting source, Raman gain spectrum and small signal amplification spectrum of optical fiber are measured by optical spectrum analyzer Q8384. The hybrid FRA has gain bandwidths of 88 nm in S and C band. It will increase the transmission channels of fiber communication network.

Keywords Fiber Raman amplifier; Dispersion compensation; Hybrid FRA; Gain; Gain bandwidth
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0 Introduction

With the increasing demand for transmission capacity on optical fiber communication network, Raman amplifiers have been of recent research hot topic due to their capability to synthesize a gain spectrum with wide bandwidth and multiple pump sources. Dispersion compensation fiber (DCF, consisting of GeO_2) Raman amplifier especially has shown significant potential with a high signal gain and dispersion compensation of network[1,2]. The Raman backscattering effect has been applied to fiber-optical communication network to make fiber Raman amplifier.

In this letter, we report a Hybrid FRA. It consists of general fiber G652 and DCF. The optimum design of hybrid FRA has been done by using optimum design software of FRA--OptiAmplifier 4.0. The result shows that its bandwidth is 88 nm in S and C band by 1427 nm pumped fiber Raman laser.

1 The backscattering spectrum of optical fiber

When an exciting photon interacts on a fiber molecule, a phonon can be released or absorbed. There is a frequency shift $\Delta\nu$[3] between the exciting and scattering photon. It is shownin Fig. 1. The scattering photons of molecules are separated into two types:

1) Stokes scattering photon (releasing a phonon)

$$h\nu_s = h\nu_p - h\Delta\nu \quad (1)$$

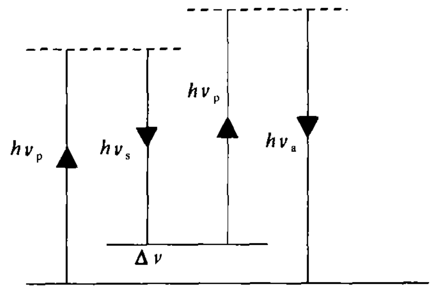

Fig. 1 Molecular vibration energy and scattering photon

2) Anti-Stokes scattering photon (absorbing a phonon)

$$h\nu_a = h\nu_p + h\Delta\nu \quad (2)$$

where ν_p, ν_s, ν_a represent frequencies of exciting, Stokes and anti-Stokes scattering photon respectively.

Fig. 2 shows the setup diagram measuring backscattering spectra of fiber. Backscattering spectra of G652(25.3 km) and DCF(5.1 km) is measured by using OSA (Advantest Q8384 optical spectrum analyzer). It is pumped by PYL-1-1427 Raman laser whose power is 100 mW. They are shown in Fig. 3 and Fig. 4. In the Stokes range[3]: Raman I band (first order Raman backscattering), frequency shift: 13.2 THz, band width: 6 THz (3 dB); Raman II band (second order Raman backscattering), frequency shift: 26.4 THz, band width: 6 THz (3 dB). The parameters of G652 are dispersion 17 ps/nm/km, attenuation 0.213 dB/km and modal field diameter 9.3 μm, and the parameters of DCF are dispersion −107 ps/nm/km, dispersion slope −0.247 ps/nm^2/km and attenuation 0.567 dB/km at 1520 nm. It is obvious that there is approximate gain and bandwidth between 25 km G652 and 5 km DCF, but dispersion can be compensated each other. The total dispersion simulated of 25 km G652 and 5 km DCF is −98 ps/nm at 1520 nm.

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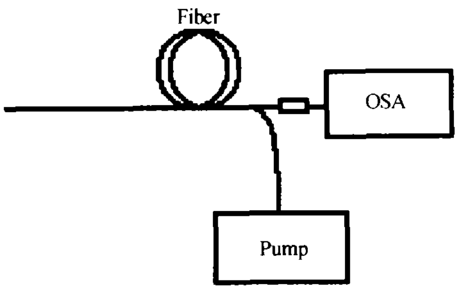

Fig. 2 Setup diagram measuring backscattering spectra of fiber

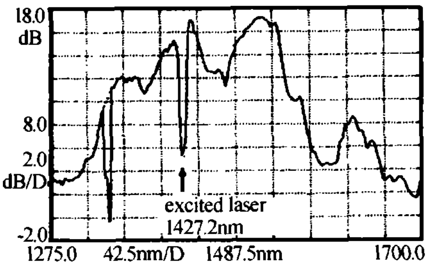

Fig. 3 Backscattering spectrum of G652 fiber

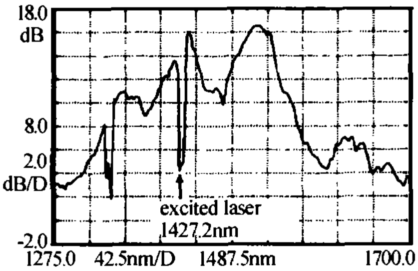

Fig. 4 Backscattering spectrum of DCF fiber

2 Fiber Raman amplifier

The Stokes Raman backscattering (signal) intensity[4]

$$I_s(L) = I_s(0)\exp(-\alpha_s L) \quad (3)$$

When pump intensity is bigger than a threshold value of stimulated Raman

$$I_s(L) = I_s(0)\exp(g_R I_0 L_{eff} - \alpha_s L) \quad (4)$$

$$L_{eff} = \frac{1}{\alpha_p}[1 - \exp(-\alpha_p L)] \quad (5)$$

Gain of FRA

$$G_A = \frac{I_s(L)}{I_s(0)\exp(-\alpha_s L)} = \exp(g_R I_0 L_{eff}) \quad (6)$$

where α_s and α_p are the fiber loss for a signal and a pump light, respectively. L is a distance of the fiber. I_0 is the pump light intensity at $L=0$. L_{eff} is fiber effective length. g_R is the fiber Raman gain coefficient.

Hybrid FRA is composed of general fiber (G652) and DCF. It includes DCF + G652, G652 + DCF and G652 + DCF + G652. The optimum design of hybrid FRA has been done by using software FRA--OptiAmplifier 4.0 (made in OPTIWAVE corporation, Canada). The best structure is G652 + DCF. The curve of gain simulated (200 mW pumped power) by soft is shown in Fig. 5. It has 6 dB gain and 80 nm bandwidth (at 3 dB). The total gain of FRA depends on fiber length. Optimum results of fiber length is 25 km G652 and 5 km DCF according to the actual materials.

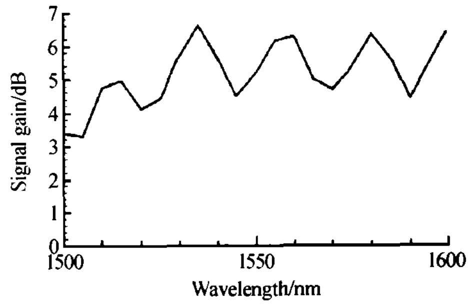

Fig. 5 The curve of gain simulated

The configuration has been set up and researched according to the optimum result. It is shown in Fig. 6. Using Raman laser (1427 nm) as an exciting source, Raman gain spectrum and small signal amplification spectrum of optical fiber is measured by optical spectrum analyzer Q8384. Fig. 7 shows the backscattering spectrum diagram of hybrid FRA at 700 mW pumped power. Fig. 8 shows its Raman amplification gain after demodulated. The hybrid FRA has gain bandwidth of 88nm (1440 ~ 1528 nm, at 3 dB) in S and C band. Its gain is higher than 20 dB. This results are near to the simulated results. It will increase the transmission channels of fiber communication network.

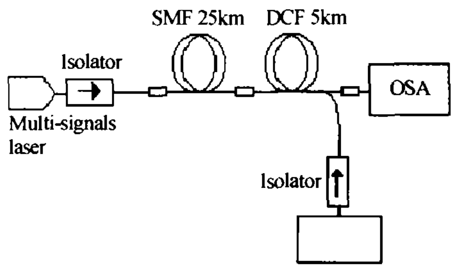

Fig. 6 Setup diagram of hybrid FRA

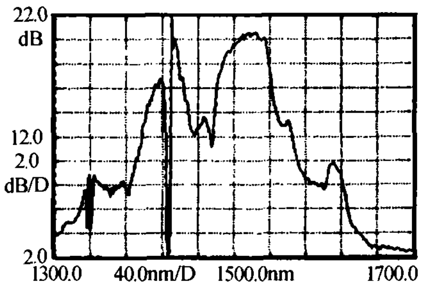

Fig. 7 The backscattering spectrum of hybrid FRA

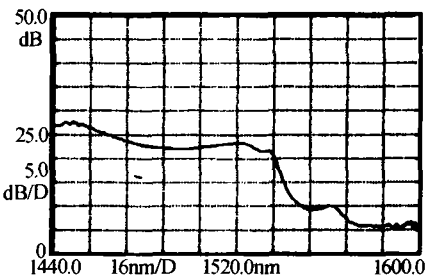

Fig. 8 The Raman amplification gain of hybrid FRA

3 Conclusion

We get the results, as follows:

1) The hybrid FRA has been measured. The pump up/on small signal gain is 22 dB at 700 mW pumped power (25.2 km G652 and 5.1 km DCF fiber).

2) The gain bandwidth of S and C band of hybrid FRA is 88 nm (1440 ~ 1528 nm). The gain bandwidth of 700 mW pumped power is flatter. Moreover the flatness will be easily improved with the aid of filter. It will improve the transmission capacity.

3) When pumped power is over 700 mW, the gain of S band exists saturation phenomena. It accords with the result of Zhang Zaixuan et al[5].

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混合型光纤喇曼放大器增益和带宽的研究

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摘 要 混合型色散补偿光纤喇曼放大器由普通G652光纤和色散补偿光纤(DCF)组成，包括:DCF + G652、G652 + DCF和G652 + DCF + G652。讨论了它们的工作原理．使用FRA-OptiAmplifier4.0软件对其进行了优化设计，最佳结构为G652 + DCF. 它可补偿光纤网络的色散，扩展通信波长范围．1427 nm的喇曼激光器作为激发源，用Q8384光谱分析仪测量了光纤的喇曼增益谱和小信号放大光谱，混合型色散补偿光纤喇曼放大器在S带和C带具有88 nm的增益带宽，这增加了光纤通信网络的传输通道．

关键词 光纤喇曼放大器;色散补偿;混合型光纤喇曼放大器;增益;增益带宽

Jin Shangzhong received his M. S. degree from Zhejiang University in 1986. He is working in Institute of Opto-electronics Technology of China Institute of Metrology as a professor. Now, he is a Ph. D. candidature at Zhejiang University. His research includes optical fiber Bragg grating, optical fiber Raman amplifier and light radiation measurement.