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Distributed Raman fiber amplifier for S-band

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This paper presents the gain and noise figure optimization of distributed Raman fiber amplifier in S–band for single-mode fiber (SMF) and dispersion-shifted fiber (DSF) by using WDM pumping scheme. For single-mode fiber 16 dB gain with 50 nm bandwidth and for dispersion-shifted fiber 19 dB gain with 40 nm bandwidth is obtained. In both cases noise figure is also achieved.

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Keywords: Raman fiber amplifier, Single-mode fiber, Dispersion-shifted fiber and WDM pumping

1. Introduction

The dense wavelength division multiplexing (DWDM) systems are demanded continuously to increase the channel capacity and transmitting distance due to rapid growth of the data and internet traffic. It means broadening of available bandwidth and increasing its amplifying span is necessary. Now days WDM transmission is using up the entire gain band of Erbium-doped fiber amplifier (EDFA) i.e. C-band and L-band. Even though the entire band of the EDFA is fully utilized and very high spectral efficiency was obtained through soliton technology, demands from internet still seem to keep on growing recklessly. Infact EDFA-based WDM transmission technology has been hitting the upper limit of transmission capacity [1-3].

Erbium-doped fiber amplifiers are lumped amplifiers in which gain is lumped at a point of the transmission line. The distributed amplifier such as Raman fiber amplifier keeps the optical signal level over a long distance along the transmission line. The Raman fiber amplifier offer gain at any wavelength so long as a suitable pump laser can be found at appropriate wavelength. This characteristic is helpful in broadening the available bandwidth. Raman fiber amplifier has some outstanding advantages, such as the seamless gain over wide bandwidth, remarkable noise reduction, extension in the span length and better nonlinear impairments of transmission systems [3-5].

Raman amplifiers use stimulated Raman scattering in silica glass fiber, which is inelastic scattering of a photon with a molecule. The interaction between the incident photon and molecule will cause the molecule to vibrate, resulting in the frequency down shift or stokes shift of the photon for the sake of energy conservation. Quantum mechanically this process is described in Fig. 1.

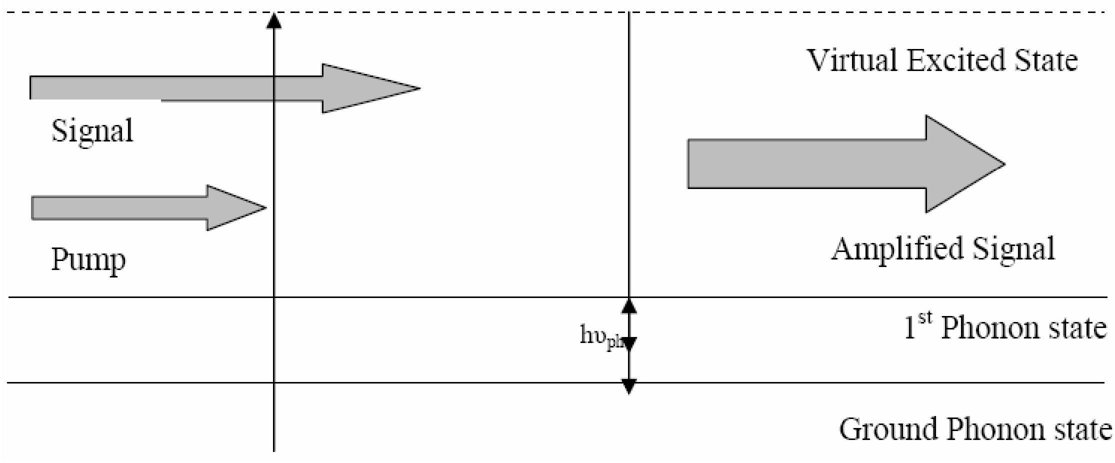

Fig. 1. Quantum mechanical description of stimulated Raman scattering process.

In small signal gain region, the coupled rate equations for pump and signal light can be described as under [6-7]

$$\frac{dI_S}{dz} = g_R I_P I_S - \alpha_S I_S \tag{1}$$

$$\frac{dI_P}{dz} = -\frac{\omega_P}{\omega_S} g_R I_P I_S - \alpha_P I_P \tag{2}$$

Where z is distance, I_P and I_S are the intensity of pump and signal light, g_R is the Raman gain coefficient, α_P and α_S are the fiber loss coefficient at pump and signal wavelength respectively and ω_P and ω_S are angular frequencies of pump and signal respectively.

The above set of equations can be easily solved and the Raman gain and noise figure (NF) are given as

$$G_R = \exp(g_R I_0 L_{eff}) \tag{3}$$

and

$$NF = P_{ASE} / h\nu B_0 + 1/G \tag{4}$$

Where P_{ASE} is the amplified spontaneous emission, L_{eff} is the effective length of fiber, I_0 is pump intensity at input port, G is gain and B_0 is the bandwidth of amplifier. Raman gain spectrum of optical fiber exhibits a broad continuum shape due to amorphous nature of the material. Fig. 2 presents Raman gain spectra for different fibers [6]. The magnitude of the Raman gain is determined by nonlinearity and the profile is determined by the respective fractions of GeO_2 and silica [8-10].

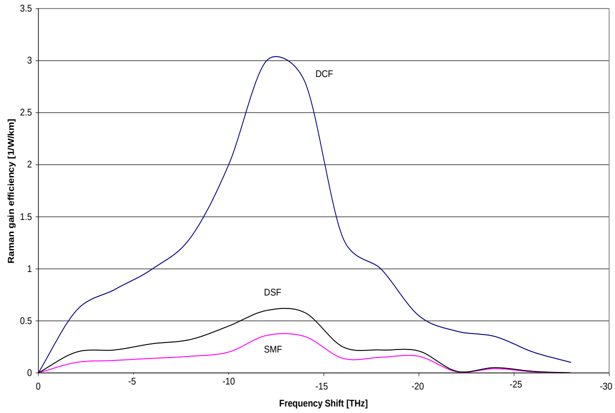

Fig. 2. Raman gain efficiency spectra for single-mode fiber, dispersion-shifted fiber and dispersion-compensating fiber.

2. System design

The schematic design of Raman amplifier for S-band region is shown in Fig. 3. The design consists of a multiple signal laser, two isolators, a WDM coupler, a Raman pumping unit and an optical spectrum analyzer (OSA). Raman gain and noise figure (NF) is obtained for both 40 km single-mode fiber (SMF) and dispersion-shifted fiber (DSF) by using the system shown in the Fig. 3. Multiple signal laser and Raman pumping unit consists of twelve laser diodes.

Input isolator prevents amplified spontaneous emission (ASE) and signals from propagating in backward direction otherwise it may reduce the gain and enhance the noise level. Backward pumping is preferred for amplification because it results in better quantum conversion efficiency and noise figure.

The computer simulation is carried out by using opti-amplifier software. This software utilizes coupled rate equations for calculation.

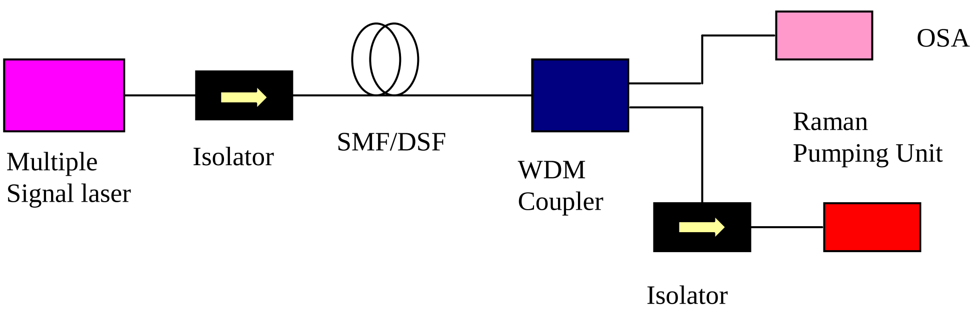

Fig. 3. Schematic design of Raman amplification in S-band for single-mode fiber and dispersion shifted fiber.

3. Results and discussion

The Raman gain and noise figure is measured in S-band region for single-mode fiber and dispersion-shifted fiber. Each fiber type is taken 40 km in length. For optimization of gain and noise figure, multiple signal laser (in count 12) each with line-width 0.1 nm is used. Each signal laser is launched with -60 dB power.

In case of single-mode fiber total pump power utilized by Raman pumping unit is about 943 mW. The composite flat Raman gain can be obtained by simply adjusting the pump powers and respective pump wavelengths. In this case a 16 dB gain with almost 50 nm flat bandwidth is obtained. For dispersion-shifted fiber a 19 dB gain with about 40 nm flat bandwidth is obtained by utilizing 833 mW pump power. Higher Raman gain efficiency results in higher gain in case of dispersion-shifted fiber. Gain ripples for single-mode fiber and dispersion-shifted fiber are ±0.7 dB and ±0.5 dB respectively. These results are shown in Fig. 4.

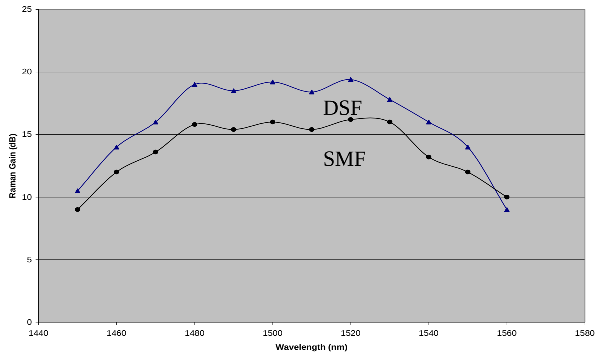

Fig. 4. Raman gain for single-mode fiber and dispersion-shifted fiber in S-band region.

Noise figure in both cases is high in lower signal wavelength region because higher pump powers are utilized in this region. Thermal instabilities, pump-to-pump Raman interaction and power fluctuations in pump are also responsible for increasing the noise figure in lower signal wavelength region. The noise figure is below 7 dB for dispersion-shifted fiber and it is below 6 dB for single-mode fiber over entire band as shown in Fig. 5.

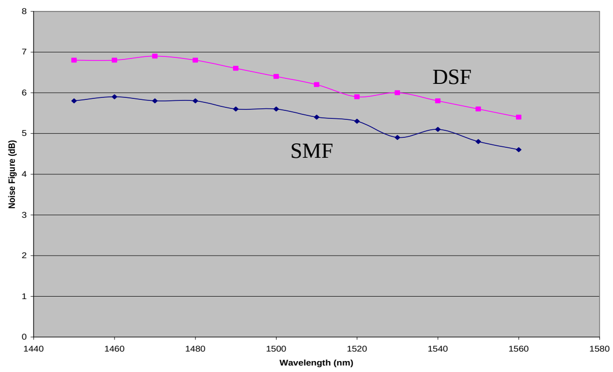

Fig. 5. Noise figure spectrum for single-mode fiber and dispersion-shifted fiber.

4. Conclusion

The optimization of Raman gain and noise figure in S-band region is carried out for 40 km length of single-mode fiber and dispersion-shifted fiber separately. For single-mode fiber a gain of 16 dB with 50 nm flat bandwidth is obtained while it is 19 dB and 40 nm for dispersion-shifted fiber. The noise figure is below 7 dB for dispersion-shifted fiber while it is below 6 dB for single-mode fiber.

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