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Raman amplification in U-band

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The gain and noise figure of Raman amplifier in U-band region for single mode fiber (SMF) and dispersion shifted fiber (DSF) with simple WDM pumping scheme is presented in this paper. For SMF a 17 dB gain with 45 nm bandwidth and for DSF, a 27 dB gain with 42 nm bandwidth is obtained in U-band. Gain flatness is achieved with a ladder shape designed filter.

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1. Introduction

Rapid developments in WDM transmission systems have increased the transmission capacity of fiber-optic communication tremendously [1]. At least, in principle, broad-band amplification by Fiber Raman amplifier (FRA) can be obtained at any wavelength. WDM systems with repeater less 40 Gb/s transmission of S-C- and L-band channels over 135 km have been reported [2]. Due to lowest signal loss many long-haul transmission experiments concentrated on wavelength range from 1530-1610 nm i.e. C+L band. The larger capacity systems can be realized by optimization of pump power which ultimately results in extension of optical bandwidth to new bands such as S-band (1480-1520 nm) and U-band (1625-1675 nm) [3, 4].

To provide cost-effective network capacity for larger bandwidth demand, higher bit-rate and higher channel capacity systems are being rapidly developed. Optical amplifiers have played a very critical role in telecommunication revolution. Light wave communication system using in-line amplifier can operate over multiple fiber spans without expansive electronic regenerator among various competing candidates for next generation optically amplified transmission systems Fiber Raman amplifiers with distributed gain along fiber transmission lines offer the necessary low noise amplification for economical field-deployment.

When an optical field is incident on a molecule, the bound electrons oscillate at optical frequency which results in induced oscillating dipole moment. This generates sum and difference frequency terms between the optical and vibrational frequencies giving Raman scattered light in the re-radiated field [5, 6].

In quantum mechanical description (Fig. 1), optical photons are inelastically scattered by quantized molecular vibrations called optical phonons. Photon energy is lost or gained shifting the frequency of the light. The components of scattered light that are shifted to lower frequencies are called Stokes lines; those shifted to higher frequencies, anti-Stokes lines. The shift is equal to the oscillating frequency of the lattice phonon that are created or annihilated. The anti-Stokes process is much weaker than Stokes process in the context of light wave communication. Raman scattering can occur in all materials, but in silica glass the dominant Raman lines are due to bending motion of the Si-O-Si bond. The Raman scattering can also be stimulated by signal light at an appropriate frequency shift from pump. In this process, pump and signal light are coherently coupled by the Raman process. This process is nonresonant because the upper state is short-lived virtual state. Therefore it is a fast process which results in increased efficiency (Fig. 2) leading to utility of Raman amplifiers for fiber span of several kilometers [5-7].

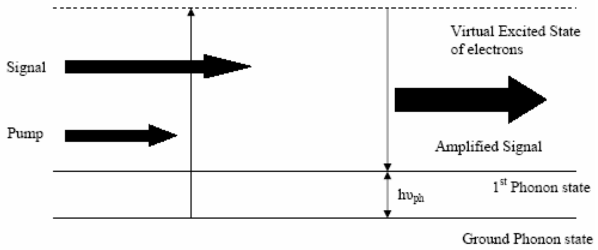

Fig. 1. Quantum mechanical picture of SRS process.

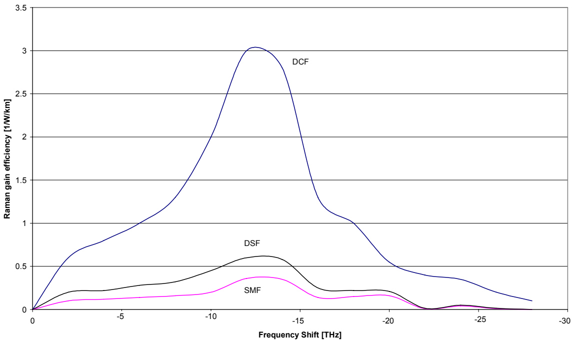

Fig. 2. Raman gain efficiency spectra for SMF, DSF and DCF.

There are many pumping schemes for broad-band Raman amplifiers. In one approach, pumps at fixed wavelengths are time-division multiplexed so that one pump or a set of pumps are on at any given time [8]. L.F. Mollenauer et al utilized a single pump with rapidly and repeatedly swept over the necessary wavelength range for broad-band amplification [9]. Many researchers employed high-order pumping schemes for unrepeatered transmission [10-12].

To optimize the Raman gain in U-band, a simple WDM pumping scheme is chosen here. This scheme is cost-effective, practical and robust with facility of system upgradation. For this pumping scheme a set of pumps operating at different wavelengths are combined through WDM couplers into a single fiber to realize a composite flat Raman gain.

2. Experimental set-up

The schematic diagram for Raman amplification in U-band is shown in Fig. 3. The system for gain and noise figure optimization consists of a multiple signal laser source, two isolators, a WDM coupler, a multiple pump laser (in count-12) and a optical spectrum analyzer. The gain and NF are calculated for SMF (30 km) and DSF (30 km). Input isolator prevents ASE and signals from propagating in backward direction. Otherwise it may reduce population inversion which leads to reduction in gain and enhancement in noise figure. Backward pumping is preferred for Raman amplification because it gives better conversion efficiency and noise figure. To flatten the gain spectrum we employed a designed two step ladder shape gain flattening filter.

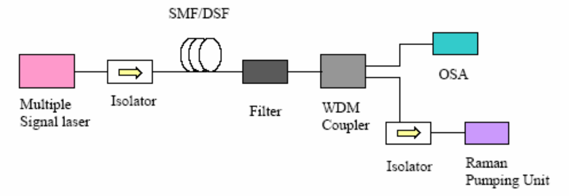

Fig. 3. Schematic diagram for Raman amplification in single-mode fiber/ dispersion shifted fiber.

3. Results and discussion

To evaluate the gain and noise performances in U-band region, gain and noise figure are measured as function of signal wavelength for both SMF and DSF of length 30 km each. In case of SMF multiple signal laser (each with line-width 0.1 nm) is used with -60dB power each. Raman pumping unit consists of 12 pump LDs with total power almost 986 mW. By simply adjusting the pump wavelengths and pump powers, a 17 dB gain with gain flatness of 45 nm is obtained. In this case gain ripple of almost ±0.8 dB is observed. Raman gain in DSF is as high as 27 dB with 42 nm flatness and gain ripple is about ±0.6 dB. For same signal power and wavelength 882 mW pump power is needed for DSF [Figs. 4, 5].

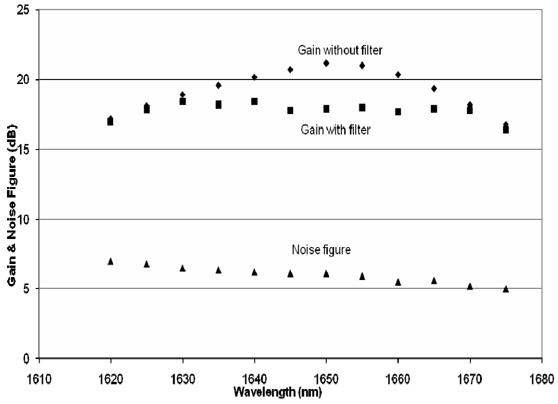

Fig. 4. Raman gain and noise figure spectrum for single-mode fiber.

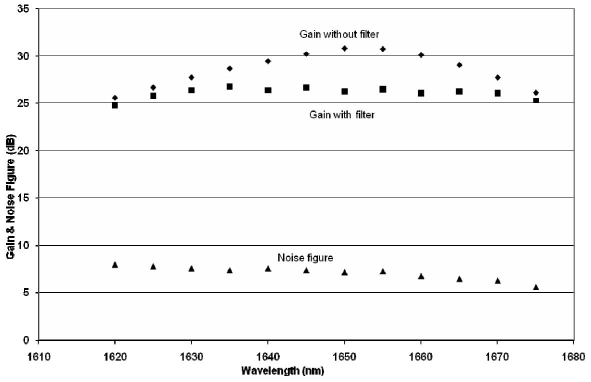

Fig. 5. Raman gain and noise figure spectrum for dispersion-shifted fiber.

In case of DSF gain is high as compared to SMF because of lower effective cross sectional area and higher Raman gain efficiency. Noise figure in both cases is slightly high in lower signal wavelength region because of allocation of higher pump energy in this range. Thermal instabilities, pump-to-pump Raman interactions and power fluctuation in pumps result in more NF in lower signal wavelength region. Over entire signal band noise figure is well below 7 dB for SMF and it is below 8 dB for DSF. In order to make Raman gain flat, a ladder shape gain flattening filter is used. However the use of such components leads to the lower efficiency and higher cost.

4. Conclusion

The gain and noise figure optimization for Raman amplifier, in U-band region, using 30 km SMF and DSF is carried out with simple WDM pumping scheme. A gain of 17dB with 45 nm gain flatness is obtained for SMF. In case of DSF gain is 27 dB with 42 nm flatness. Gain ripple is 0.8 dB and 0.6 dB for SMF and DSF respectively. Over entire signal band noise figure is below 8 dB for DSF and below 7 dB for SMF. It can be observed that U-band Raman amplification for SMF and DSF is almost as effective as L-band Raman amplification

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