International Research Journal of Natural and Applied Science
ISSN: (2349-4077)
Impact Factor 5.46 Volume 4, Issue 9, September 2017

Co-axial Fiber Design for Inherently Flatten Raman Gain Spectra

Asad Ali Khan[1], Anuj kumar Agarwal[2], Anil Kumar[3*]

[1]Department of Physics, Teerthanker Mahaveer University, Moradabad (U.P.)

[2]Department of Physics, Teerthanker Mahaveer University,Moradabad (U.P.)

[3]Department of Physics, Hindu College, Moradabad (U.P.)

Abstract

The novel and innovative fiber design, namely co-axial fiber design is proposed, which can provide inherent flattening of Raman gain along with broadband dispersion compensation over about 30-nm bandwidth. We present here the basic principle of Raman gain flattening in this design, followed by detailed modeling, numerical result and discussion for each of the fiber design.

Keywords: Raman amplifier, Co-axial fiber, Raman gain, DCRA.

1. INTRODUCTION

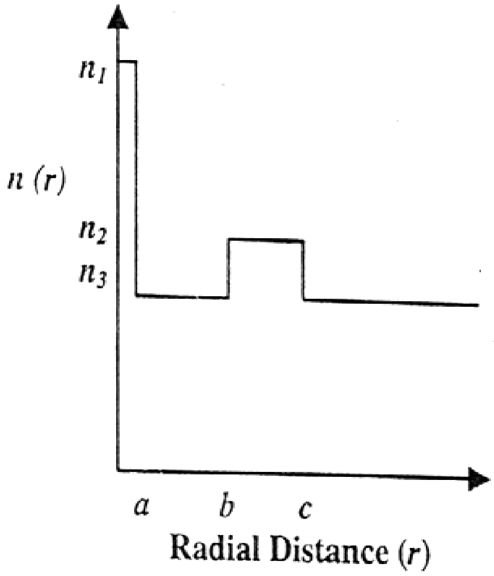
Wavelength division multiplexing (WDM) is the most favourable solution for increasing interest for higher transmission capacity in optical fiber networks. Since the power of WDM systems is restricted by the band width (~30 nm in C-band of wavelength) of Erbium doped fiber amplifier (EDFA). The gain flatten Raman fiber amplifiers, exploiting novel wavelength bands, have become as a solution with this restriction. The gain band of Raman fiber amplifiers is calculated by the wavelength of pump only, by which it is simpler to obtain amplification in conventionally S like bands. The Raman gain coefficients per unit effective area is called effective Raman Gain [1, 2]. This technique needs complicated design processes for getting the proper wavelength. Also, the number of pumps used is directly related to the gain flatness and thus, it is highly costly technique to apply. It has also been shown in literature that longer is the span length (i.e. more is the required on-off gain), more is the number of pumps required for obtaining same flat-gain bandwidth [3].

We propose a novel co-axial fiber design for getting flatten gain Raman amplification for any wavelength band by using a signal pump only [4, 5]. It is for the first time, to the best of our knowledge, that a technique for inherent Raman gain flattening has been proposed. The property of designed coaxial fiber is that the spectrum of the effective Raman gain is obtained inherently flatten for a varying wavelength range. Our fiber design consists of a large negative dispersion coefficient such that the link dispersion is not compensated only but is also be made flatten. Detailed simulations are presented here by considering and counting the splice losses which depend on wavelength at the splices of input and output.

Since the wavelength dependent attenuation provides a loss-less, dispersion flattening dispersive compensating module for S band that depends on our proposed fiber design. An amplifier having a flat Raman gain over 32 nm band width from 1480 nm to 1511 nm consists of $\pm$ 0.2 db ripple, when single pump is being used, is discussed here. We compare the power amplifiers for lossless dispersion compensating module with the dispersive compensating Raman amplifier (DCRA) module has been discussed. therefore, it is clear that the designed module is much better and cheap for long haul system. The performance of the proposed co-axial fiber design is restricted due to significant number of modes (around 6) and it helps in the wavelength regime of operation. The fiber is designed in such a way that at the output of the amplifier, the power contained in the higher order super mode is at least 12 db loss than that in the fundamental range of operation. The fiber also possesses a large, slowly changing negative dispersion coefficient in the wavelength range. Simulations for modeling the model field profile of the fiber, the characteristics of amplifier and dispersion properties have been discussed, which show that the designed fiber is used for getting a better broadband, loss-less module having dispersion-compensating.

2. BASIC PRINCIPLES OF CO-AXIAL FIBER DESIGN

in figure 3.1 the refractive index profile of designed fiber is shown, consisting of a dual core that is proposed [6] for obtaining a flattened dispersion for broadband compensation.



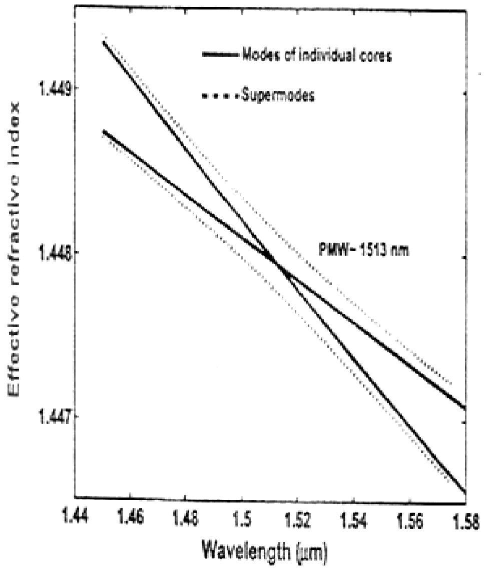


Fig. 1: Refractive index of a coaxial fiber design

Fig. 2: Effective refractive indices of coaxial fiber

It has concentric dual cores in which the inner core has a large Δ and the outer core has a small Δ, where Δ is expressed as $(n_i^{2-}n^{3}_{3})/2n_3$; n_3 represents the pure silica refractive index [21] and i1, 2 represents to inner and outer cores respectively. The parameters of dual cores are selected such a way that each works as a single azimuthally symmetric mode (LP_{o1}) in wavelengths operating regime. The co-axial fiber design can be perceived as a directional coupler formed by the inner side core and wavelength for which phase of both mode of the individual cores are matched (i.e. they have same effective refractive indices) can be termed s phase matching wavelength (PMW). The l = 0 super mode of the structure are similar to the symmetric and anti-symmetric mode of the directional coupler. In our proposed co-axial fiber, the both inner and outer modes are phase matched at around 1513 n (Fig. 2). In Fig. 2, the solid line represents the modes of the core of the fiber, and the dotted lines represents the super modes of the combined structure.

From fig. 2, we observe wavelengths that are much less than the phase matching wavelength (PMW), the refractive index of basic super mode is near to the refractive index of the individual mode of the dual inner side core. Therefore, the model field at the pumping wavelength and the signal wavelengths below PMW shall be firmly wound around the inner side core, develop a high pumping signal overlapping, so that less value of A_{eff} is obtained, if the basic mode will slowly increases in the outer side core. Therefore, the overlapping in pumping and the signal field begins to low, with enhancing the effective area. Therefore, by selecting the fiber parameters properly, wavelength of phase matching and the wavelength of pumping, this is ensured that the decrement in A_{eff} is able to compensate the decrement in the Raman gain coefficient, so that a flatten gain spectra is obtained. However, losses which depends on some wavelengths when the fiber works as an amplifier, the fiber parameters decide the flatness of the amplifier gain, more than effective Raman gain spectra. Due to nonlinear spectral changes in the effective index of the fundamental super mode, the mode possesses a large dispersion.

3. MATHEMATICAL MODELLING

For multi-layered fiber profiles, the bulk Raman gain coefficient g_R is also a function of radial co-ordinate, so that effective Raman gain coefficient Υ_R are represented as;

$$\gamma_{\mathrm{r}} = \frac{\int\int gr(r)\Psi_p^2 \Psi_s^2 \, r \, dr \, d\emptyset}{\int\int \Psi_p^2 r \, dr \, d\emptyset \int\int \Psi_p^2 r \, dr \, d\emptyset} \tag{3.1}$$

In our calculation, Rayleigh scattering of signal (single and double) is considered but Rayleigh back scattering of ASE noise is treated as negligible, because of its negligible contribution. Due to ASE, the Pumping and signal depletion and signal to signal power transfer because of Raman scattering is also become negligible. The assumptions considered for a Raman fiber amplifier of relatively less gain and relatively short fiber length. In fig. 3, the configuration of the proposed lossless dispersive compensating Raman amplifier (DCRA) is shown.

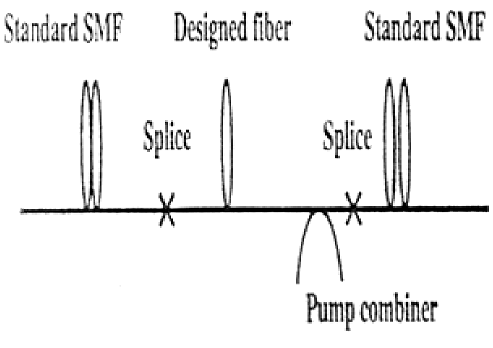


Fig. 3: Device configuration for proposed DCRA

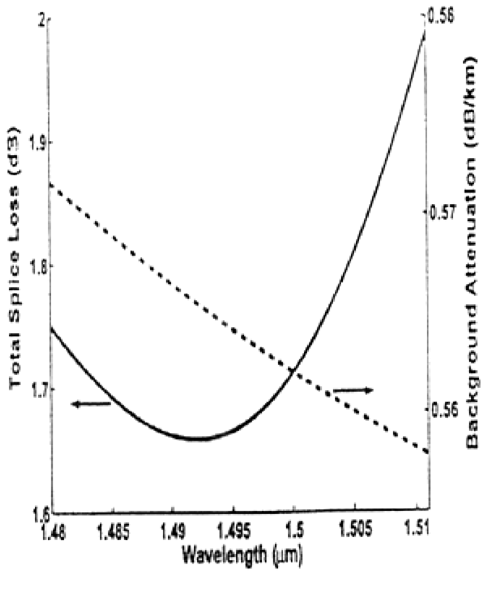


Fig. 4: Spectral variation of splice and background losses

The Raman amplifier is applied in a transmission link, on both the ends, the proposed fiber is spliced to a standard single mode fiber. To modify the amplifier parameters desired to obtain a flatten gain, splice losses and background attenuation are the losses which depend on wavelength that require for caring this configuration.

The parameters of the designed fiber are Δ_1=2.0%, Δ_1=0.3%, a=1 µm, b=7.9 µm and c=15.5 µm. In Fig. 4, the dashed curve elaborates the spectral changes in the background attenuation coefficient of fiber. Here, we discuss the values of attenuation coefficients for having fiber with high delta, around 0.55 db / km at 1550 nm [7], and we consider that the spectral changes of attenuation will be identical as for a G.652 fiber. The power joined from a G.652 fiber with a co-axial fiber is discussed by the formula [8]. The splice losses both input and output side splice, is expressed by $T = -20\log_{10}\boldsymbol{n}$. To decrease the splice losses and their spectral change, we taper the G.652 fiber by 40% of the amount. The taper effect is modeled according to scaling of fiber dimensions. This result the dispersion of mode field order of G.652 fiber, has become a better overlapping with the basic super mode field of co-axial fiber and the splice losses spectral variation are significantly decreased. In Fig. 4, the solid curve describes the splice loss changes in the wavelength operating range. By considering the effect of losses depending on wavelength in analysis proposed, we tune the fiber parameters iteratively in such a way that the output gain spectra become flatten.

In figure 5 the spectral variation of g_R for the inner core region (for a depolarized pump) are shown and A_{eff} of proposed fiber.

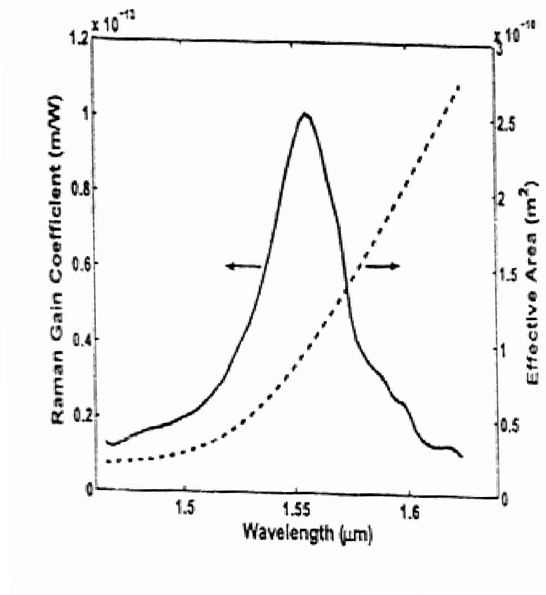


Fig. 5: Spectral variation of $g_{R.}$ and A_{eff}

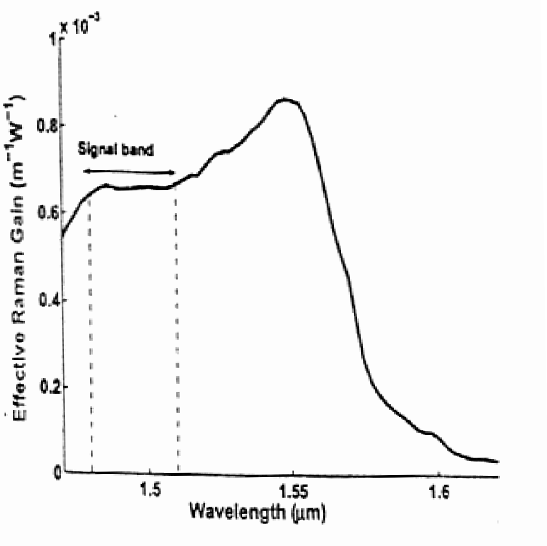


Fig. 6: Spectral variation of Υ_R

It is obvious that for wavelengths smaller than the peak gain wavelength, the changing in A_{eff} nearly obeys that of $g_{R.}$ and this is become an effective Raman gain coefficient Υ_R which is made flatten for the given wavelengths. Since the losses which depend upon wavelength, the fiber parameters and the pumping wavelength are selected in such a way that Υ_R is not obtained clearly flat. In figure 6, the effective Raman gain spectra of the fiber is shown.

The gain spectra for the output of the proposed amplifier is shown in figure 7, which is related to the simultaneous input having 32 WDM channels in the operating range from 1480 to 1511 nm for 0.1 mW power per channel (solid curve) and 1 mW power per channel (dashed curve). From Fig. 7, it is observed that a flatten gain having ± 0.2 db gain ripple is obtained for band width of 32-nm. This can also be verified that a high and spectrally flat OSNR greater than 35 db is obtained.

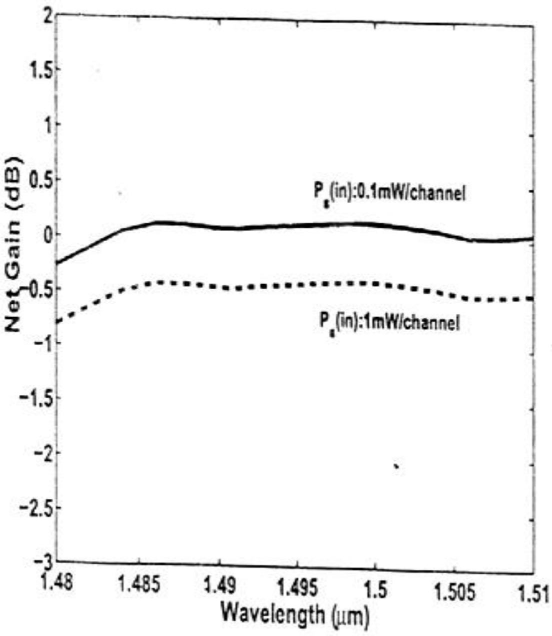


Fig. 7: Net gain of the designed Raman Amplifier

The dispersive curve of the proposed Raman fiber amplifier and for a single mode fiber amplifier is shown in figure 8.

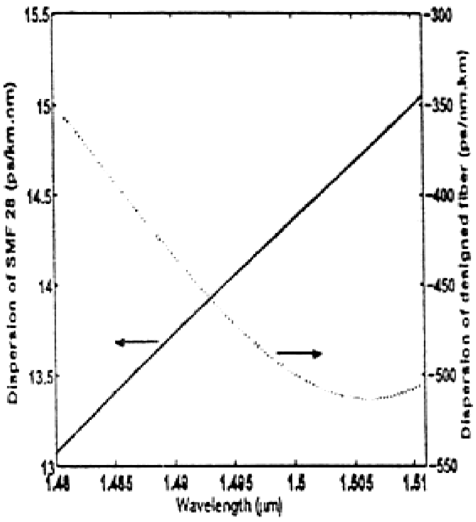


Fig. 8: Variation of dispersion coefficient

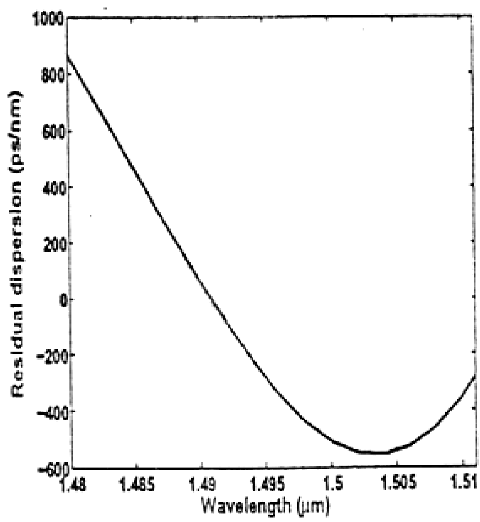


Fig. 9: Residual dispersion

Our proposed fiber is having negative dispersion coefficient over an operating range of -(380-515 p s/ km, therefore, the total link dispersion is well accumulated in 5 spans of transmission and can be compensated by 12.5 km fiber length. Because of the parabolic structure of the dispersion curve obtained, we are able to compensate for dispersion but also able to make flat it. The dispersion after 5 spans of transmission fiber and 12.5 km of proposed fiber is shown in Figure 9. Here the dispersion can be compensated to within the limit ± 1000 ps / nm for an operating wavelength range from 1480 nm to 1511 nm.

4. TOLERENCE ANALYSIS

The performance of our proposed module is well tested with respect to the changing in fiber dimensions and refractive indices. Figures 10 and 11 shows the changes in net gain spectrum with variation in fiber dimensions and refractive indices respectively.

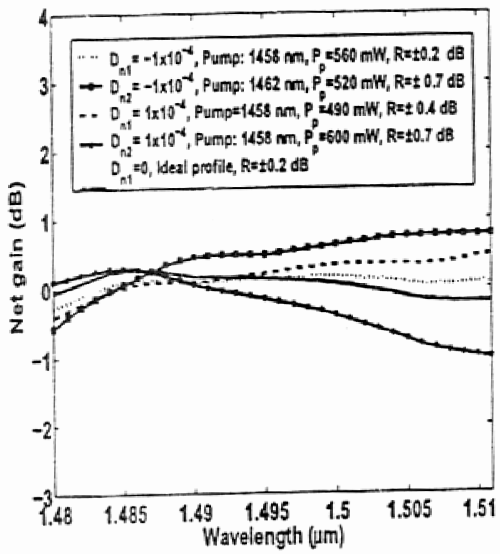


Fig. 10: Variation in gain spectra with refractive index

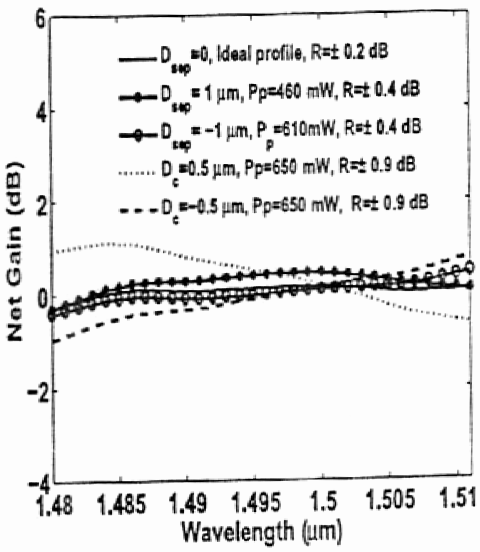


Fig. 11: Variation in gain spectra with fiber dimensions

Here D refers to a deviation in fiber parameter under consideration; for example $D_{n\ 1}$ is the deviation in refractive index $\boldsymbol{n}_1$ and D_{scp} is the deviation in the separation b-a, keeping the rest of the parameters to be the same. Here P_p and λ_p denote the pumping power and operating wavelength respectively. The amplifying fiber length and the input conditions (signal wavelength and powers) are considered same in each of the case. R denotes the gain ripple in each case and we note that for ± $1x10^{-4}$ changes in refractive indices and > ±0.5 µm deviation in dimensions, the gain ripple is less than ± 0.9dB in each case. In case of random fluctuations along the length of the fiber, with values ranging within the extreme deviations considered above, we expect the results to be better than the ones for extreme cases.

5. RESULTS AND DISCUSSSION

The analysis shows that distance between two cores is not an important parameter, as we maintain the gain flattening for the same wavelength band. The tolerance results with respect to core radius and refractive indices are found similar to that of co-axial fiber design.

We compare the performance of the Co-axial designed modules with that of a typical conventional dispersion compensating Raman amplifier (DCRA) modules. For lossless dispersive compensation of span (approximate 80 km) of SMF28 fiber, a DCRA module with 16-17 km of broadband DCF, multiple pump configuration and a total ~ 350 mW of pumping power is required. For every SMF28 transmission span, this DCRA module is required, that is, for getting lossless compensation of 5 spans of transmission, we need exactly five times of components and five times the pump power. Therefore, we can say that the proposed module (e.g. that based on co-axial fiber) requires 12.5 km of proposed fiber and 520 mW pumping power, without any external filter and gain flattening unit, for lossless dispersive compensation of 05 SMF28 transmission span. Therefore, it is concluded that that the our modules are better and having low cost for long haul transmission systems.

In our proposed modules, the wavelength region of working of simultaneous dispersion compensation and gain flatten Raman amplification is shifted towards any suitable wavelength range by changing fiber parameters and wavelength of the pump. In our proposed designs, germania is considered as the dopant in the core, the effective Raman gain of the fiber is however low ($< 1 \times 10^{-3}\, W^{-1}\, m^{-1}$). Although the inherently Raman gain flatten technique can be applied into fibers consisting of greater Raman gain coefficient dopants, like tellurite [9], and broadband discrete Raman amplifier having greater inherent flat gain may be obtained.

6. CONCLUSION

We have presented a novel co-axial fiber design to obtain inherently flat Raman gain spectra along with simultaneous broadband dispersion compensation. Changing the spectral variation of Raman effective area has been to obtain inherently gain flatten in the proposed fibers. Tapping the fiber characteristics, we have designed lossless, broadband dispersion compensating modules based on the proposed fibers, where the lossless operation is obtained by inherent gain-flatten Raman amplification.

References

[1] Emori, y. & Namiki, S. (1999), '100 nm bandwidth flat gain Raman amplifiers pumped and gain-equalized by 12-wavelength-channel WDM high power laser diodes', *Proc. Optical Fiber Commuination Conference.*

[2] Perlin, V. E. & Winful, H. G. (2002*b*)', Optimal design of flat-gain wide-band fiber Raman amplifiers', *Journal of Lightwave Technology* 20, 250-254.

[3] Liu, X. & Li, Y. (2003), 'Optimizing the bandwidth and noise performance of distributed multi-pump Raman amplifiers', *Optics Communications 230, 425-431.*

[4] Thyagarajan, K., & Kakkar, C. (2003), Fiber design for broadband, gain-flattened Raman fiber amplifier', *IEEE Photonics Technology Letters* **15,** 1701-1703.

[5] Thyagarajan, K. & Kakkar, C. (2004), 'Novel fiber design for flat Raman amplification using single pump and dispersion compensating in S band', *Journal of Lightwave Technology* **22,** 2279-2286.

[6] Palai, p., Varshney, R. K. & Thyagarajan, K. (2001), 'A dispersion flattening dispersion compensating fiber design for broadband dispersion compensation', *Fiber and Integreted Optics 20* , 21-27.

[7] Lewis, S., Chernikov, S. V. & Taylar, J. R. (2000), 'Broadband high-gain dispersion compensating Raman amplifier', *Electronics Letters 36, 1355-1356.*

[8] Ghatak, A. & Thyagarajan, K. (1998), University *Introduction to Fiber Optics, Cambridge Press.*

[9] Mori, A., Masuda, h., Shikano, K. & Shimizu, M. (2003), 'Ultra-wide-band telluritebased fiber raman amplifier', *Journal of Lightwave Technology 21, 1300-1306.*