Delta University Scientific Journal
Journal home page: https://dusj.journals.ekb.eg

# Variation of the Raman Amplifier Gain for 48 Channels (100 GHz, Wavelengths from1529.55 to 1567.13 nm)

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**ABSTRACT**

The performance analysis of a Raman scattering amplifier based on Germania-doped silica fiber shows that the gain (G) of each channel depends significantly on the channel central wavelength ($\lambda_{ch}$), the pump wavelength ($\lambda_p$), and the Raman amplifier length (L). The gain for each channel is influenced by Raman amplifier parameters such as the Raman gain coefficient ($g_r$) and the attenuation coefficient ($\alpha$), both of which are functions of the channel wavelength. Additionally, the refractive index of the fiber material is affected by $\lambda_{ch}$.

The final gain for the three types of pumps is evaluated based on published references. The attenuation of the pump signal remains constant when the pump wavelength ($\lambda_p$) is constant. However, the attenuation of the channel signals decreases with increasing wavelength up to 1550 nm and then increases for wavelengths greater than 1550 nm. In this wavelength range, the Raman gain coefficient ($g_{rxT}$) decreases. The final gain is independent of the type of pump (forward, backward, or dual).
For instance, with a core radius (a = 3.5 µm), a Germania dopant ratio (x = 3%), $\lambda_p$= 1.48 µm, a temperature of 300 K, and L = 50 km, the gain for channel 1 ($G_{ch1}$) is 622.7, while for channel 48 ($G_{ch48}$) it is 503.7, resulting in a variation rate ($R_v$) of -19.11%. At L = 100 km, the gain for channel 1 ($G_{ch1}$) is 112.81, while for channel 48 ($G_{ch48}$) it is 91.53, yielding a variation rate ($R_v$) of -18.86%. The gain decreases with increasing L. The maximum gain occurs with L equals the optimum Raman amplifier length ($L_{Gpeak}$). As the value of $\lambda_{ch}$ increases, the gain of each channel in the 48-channel WDM system (for wavelengths ranging from 1529.55 to 1567.13 nm) decreases.
The channel bandwidth ($\Delta F$) also decreases with increasing $\lambda_{ch}$. The bandwidth decreases from $\Delta F_{ch1}$ = 99.9694 GHz to $\Delta F_{ch48}$ =95.3282 GHz.
It is essential to consider the dependence of the channel gain on the central wavelength of the channel when designing optical communication links.

***Keywords:*** *Raman scattering amplifier, Germania-doped silica fiber, Channel gain, Attenuation coefficient, Wavelength dependency and WDM*

## 1. Introduction

Raman amplifier is widely used with optical telecommunication systems [1-3]. Raman gain occurs by transfer of power from optical pump (which has power, $P_p$, at wavelength, $\lambda_p$) to the optical signal (which has power, $P_s$, at wavelength, $\lambda_s$) with condition $\lambda_p < \lambda_s$ [4].
The minimum attenuation coefficient of Germania doped silica fiber ($\alpha_{min}$ occurs at $\lambda_{\alpha min}$ around 1.55μm). As $\lambda_p$ increases, the value of $\alpha_p$ decreasing because of $\lambda_p$ usually less than $\lambda_{\alpha min}$.
The net Raman amplifier gain (G ) decreases exponentially with the product of $\alpha_s$ L (where $\alpha_s$ is the attenuation coefficient for signal at $\lambda_s$ and L is the amplifier length). But G increases exponentially with the product of $g_{rxT}$ $L_{eff}$ (where $g_{rxT}$ is the Raman scattering gain and $L_{eff}$ is the effective Raman scattering length) until the gain saturation ($G_{sat}$).
As the effective fiber core area ($A_{eff}$) increases ($A_{eff}$ increases with $\lambda_s$ and $\lambda_p$) the value of $g_{rxT}$ decreases.
The final Raman gain with the three kinds of pumps (forward pump, $G_F$, backward pump, $G_B$, and dual pumps, $G_D$ ) are equally.
Within the wavelength λ=1527.55 to 1567.13 nm, as the channel wavelength increases, the final output gain decreases. Therefore, there is a variation of the output gain of the input channels.
The power transferred between lower signal wavelengths to higher signal wavelengths due to the stimulated Raman scattering is neglected.
**In this study**, the general gain formula of the Raman amplifier is analyzed as a function of the structure parameters (Germania rato,x, and L ) and the operating parameters ($\lambda_s$ , $\lambda_p$, T, $P_P$ and $P_s$).
The simulation results are done to study the variation of output gain from channel to another for 48 channels (100 GHz) WDM (0.8 nm band of each channel). The simulation results is done with $T=T_0=300$ °K, fiber radius, a=3.5μm , Germania ratio, x=0.03 , amplifier length , L=100 km and L=50km (optimum Raman amplifier length).

## 2. Mathematical Analysis

*2.1. Gain of Raman amplifier (G)*

From the propagation coupled equations [16] between the optical power of input signal ($P_s$) and the optical power of pump ($P_p$) and with assume that, the pump depletion $\{-\frac{\lambda_s}{\lambda_p} g_{rxT} P_s(z)\, P_p(z)\}$ [5] is very small, the signal power distribution, $P_s(z)$, of dual pumps (general formula) is derived as;

$$P_{sD}(z) = P_{s0}\, e^{-\alpha_s z} * \mathrm{Exp}\left\{\left[\frac{g_{rxT}\, P_p\,(1-e^{-\alpha_p z})}{\alpha_p}\right][\,S + (1-S)e^{-\alpha_p(L-z)}]\right\} \tag{1}$$

Where, $P_{s0}$ is the optical input signal at z=0, $\alpha_s$ ($km^{-1}$) is the attenuation coefficient for optical signal at $\lambda_s$, $P_p$ is the summation of input pumps power (forward pump, $P_{pF}$, at z=0 (in z-direction) with wavelength, $\lambda_p$, and backward pump, $P_{pB,}$ at z=L (in negative z-direction), with the same wavelength, $\lambda_p$,), $\alpha_p$($km^{-1}$) is the attenuation coefficient for optical pump at $\lambda_p$, $g_{rxT}$ is the Raman coefficient ($W^{-1}$ $km^{-1}$), S ($0 \le S \le 1$) is the ratio of pump power at z=0 to the total pump power, therefore $P_{pF}$= S $P_p$ and $P_{pB}$ = (1-S) $P_p$ and L is the amplifier length.

Notice that; if S=1 the amplifier becomes forward pump but if S=0 the amplifier becomes backward pump. Therefore Eq. 1 is used for the three kinds of pumps (forward, backward and

From Eq.1, the Raman amplifier gain, $G_D(z)$ is;

$$G_D(z) = \frac{P_{sD}(z)}{P_{sD}(0)} = e^{-\alpha_s z} * \mathrm{Exp}\left\{\left[\frac{g_{rxT}\, P_p\,(1-e^{-\alpha_p z})}{\alpha_p}\right][\,S + (1-S)e^{-\alpha_p(L-z)}]\right\} \tag{2}$$

From Eq.2, the final gain $G_D$ at z=L

$$G_D = \quad e^{-\alpha_s L} \quad \mathrm{Exp}\{g_{rxT} P_p\, L_{eff}\} \tag{3}$$

Therefore the final gain (G , gain at z = L) is independent upon the power ratio (S) and so, the final gain of forward pump ($G_F$), backward pump ($G_B$) and dual pump ($G_D$) are equally ($G= G_D=G_F=G_B$). and from Eq.3;

$$G = -4.343\, \alpha_s\; L + 4.343\, g_{rxT}\, L_{eff}\, P_p \tag{4}$$

As explained in [6]
From Eq.3, gain depends upon $\alpha_s$ , $\alpha_p$ (through $L_{eff}$) , length (L) , pump power ($P_p$) and grxt. And so these parameters are studied as;

*2.1.1 The attenuation coefficients (αs and αp)*

The attenuation coefficient of Germania doped silica fiber ($\alpha_1$) is a function of $\lambda$ , Germania ratio (x) and T as defined in [7];

$$\alpha_1 = 0.003 + \frac{0.75+66\,\Delta}{\lambda^4}\frac{T}{T_0} + 7.81 * 10^{11} e^{-48.48/\lambda} + \frac{1.542\,x\,e^{4.63/\lambda}}{60+46.6\,x} \qquad \text{(db/km)} \qquad (5)$$

Where $\Delta$ is the relative refractive index difference $\{2\Delta = 1- n^2_{clad}/n^2_{core}$ [8]$\}$ and $T_o$ is the reference temperature ($T_o$= 300°K).
Notice that, $\alpha$ (in $km^{-1}$) = 0.2303 $\alpha_1$ (where $\alpha_1$ in db/km).
For Germania doped silica fiber, there is minimum value of attenuation coefficient ($\alpha_{min}$) which occurs at wavelength ($\lambda_{\alpha min}$ ) around 1.55μm.
So, the signal attenuation coefficient ($\alpha_{s1}$ db/km) decreases with $\lambda_s < \lambda_{\alpha min}$ while, $\alpha_{s1}$ increases with $\lambda_s > \lambda_{\alpha min}$ as shown in Fig.1. While, the pump attenuation coefficient ($\alpha_{p1}$ db/km) decreases with increasing $\lambda_p$ (where usually $\lambda_p < \lambda_{\alpha min}$).

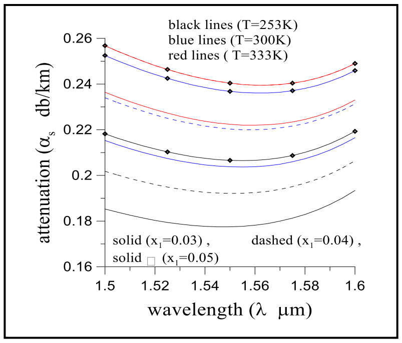



Fig.1 Attenuation of silica doped germania versus λ

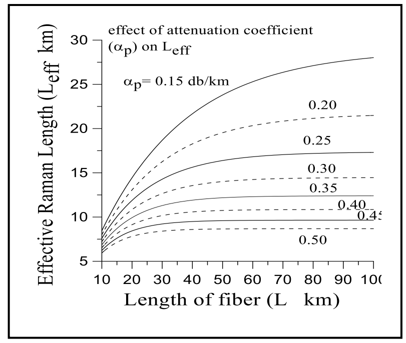



Fig.2 Effective Raman scattering length ($L_{eff}$) versus L and $\alpha_p$ (db/km) with ($T_0$=300°K), $\lambda_p$=1.48μm , a=3.5μm

*2.1.2 Effective Raman scattering length (Leff)*

Because of the pump power is absorbed through the fiber, the effective amplification length is reduced from the amplifier length (L) to the effective length ($L_{eff}$). Where $L_{eff}$ is the distance that equates a distance during which the power is transferred from the pump to the signal. It is defined as [9]

$$L_{eff} = (1 - e^{-\alpha_p L})/\alpha_p \qquad \text{km} \qquad (\text{where } \alpha_p \text{ in } km^{-1}) \qquad (6)$$

From Eq.6, the value of $L_{eff}$ increases with L but it lowering with $\alpha_p$ (Fig.2) and so, $L_{eff}$ decreases with $\lambda_p$ where usually $\lambda_p < \lambda_{\alpha mim}$.

*2.1.3 Stimulated Raman scattering gain coefficient as a function of λ (gR)*

Stimulated Raman scattering gain coefficient for pure silica, $g_{R0}$ (m/W) is defined by using the published data which stated in [10] as shown in Fig.3 and the relation between $g_{R0}$ and $\Delta k_{ps}$ (the modified wave number difference) is derived by using the fitting curve technique, $g_{R0}$ versus $\Delta k_{ps}$ is defined from Fig.3 as;

For $\Delta k_{ps}$= 50 to 200 $cm^{-1}$; with normalized error

$$10^{13} g_{R0} = 0.0237 + 0.0034\,\Delta k_{ps} - 2.385 * 10^{-5}\,\Delta k_{ps}^2 + 6.235 * 10^{-8}\,\Delta k_{ps}^3$$

For $\Delta k_{ps}$= 201 to 300 $cm^{-1}$ ;

$$10^{13} g_{R0} = -2.4733 + 0.03532\,\Delta k_{ps} - 0.0001537\,\Delta k_{ps}^2 + 2.25925 * 10^{-7}\,\Delta k_{ps}^3$$

For $\Delta k_{ps}$= 301 to 417 $cm^{-1}$ ; with normalized

$$10^{13} g_{R0} = -1.88 + 0.01145\,\Delta k_{ps} - 1.29 * 10^{-5}\,\Delta k_{ps}^2$$

For $\Delta k_{ps}$= 418 to 440 $cm^{-1}$ ;

$$10^{13} g_{R0} = 1.5565 - 0.002174\,\Delta k_{ps}$$

For $\Delta k_{ps}$= 441 to 460 $cm^{-1}$ ;

$$10^{13} g_{R0} = -0.39 + 0.00223\,\Delta k_{ps}$$

For $\Delta k_{ps}$= 461 to 535 $cm^{-1}$ ;

$$10^{13} g_{R0} = 0.4787 + 0.001635\,\Delta k_{ps} - 2.745 * 10^{-6}\,\Delta k_{ps}^2$$

For $\Delta k_{ps}$= 536 to 567 $cm^{-1}$ ;

$$10^{13} g_{R0} = 7.7912 - 0.01353\,\Delta k_{ps}$$

For $\Delta k_{ps}$= 568 to 600 $cm^{-1}$ ;

$$10^{13} g_{R0} = 0.0341 + 0.0001515\,\Delta k_{ps} \qquad (7)$$

Where, $\Delta k_{ps}$ is defined as;

$$\Delta k_{ps} = 10000\left(\frac{1}{\lambda_p} - \frac{1}{\lambda_s}\right) \quad cm^{-1} \quad \{\text{with, } \lambda_p\ (\mu m) \text{ and } \lambda_s\ (\mu m)\} \tag{8}$$

So, for $\lambda_s$=1.5 to 1.6μm and $\Delta k_{ps}$=90 to 584cm$^{-1}$ (optimum values of $\Delta k_{ps}$), the corresponding value of $\lambda_p$=1.48μm. From Eq.8, the value of $\Delta k_{ps}$ is decreasing with $\lambda_p$ while $\Delta k_{ps}$ is increasing with $\lambda_s$

* The dependence of $g_{Rx}$ on the germania doping ratio (x) is [10];

$$g_{Rx} = \frac{n_s^2}{n_1^2}\{g_{R0} + 100\, C_v\, x\, g_{R0max}\ \frac{\lambda_s^3}{\lambda_{smax}^3}\} \tag{9}$$

Where, $g_{R0max}$ is the maximum value of $g_{R0}$, $\lambda_{smax}$ is the wavelength at which $g_{R0}$ becomes $g_{R0max}$, $n_1$ and $n_s$ are the refractive indices of core and clad respectively at $\lambda_s$ and the parameter $C_v$ is defined from the published data (Fig.4 [11]) and by using the fitting curve technique, $C_v$ versus $\Delta k_{ps}$ is defined as;

For $\Delta k_{ps}$=70 to 220 cm$^{-1}$ :

$$c_v = 0.011$$

For $\Delta k_{ps}$=220 to 350 cm$^{-1}$ :

$$c_v = 0.08963 - 0.000688\Delta k_{ps} + 1.51786 * 10^{-6}\ \Delta k_{ps}^2$$

For $\Delta k_{ps}$=350 to 430 cm$^{-1}$ :

$$c_v = -0.55117 + 0.002559\Delta k_{ps} - 2.53247 * 10^{-6}\ \Delta k_{ps}^2$$

For $\Delta k_{ps}$=430 to 500 cm$^{-1}$ :

$$c_v = -0.635875 + 0.003689\Delta k_{ps} - 4.70238 * 10^{-6}\ \Delta k_{ps}^2$$

For $\Delta k_{ps}$=500 to 620 cm$^{-1}$:

$$c_v = 1.5979 - 0.008927\Delta k_{ps} + 1.718 * 10^{-5}\ \Delta k_{ps}^2 - 1.1162 * 10^{-8}\ \Delta k_{ps}^3 \tag{10}$$

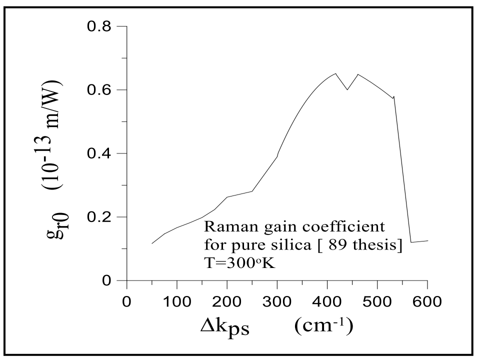



Fig.3 The value of $g_{R0}$ versus $\Delta k_{ps}$ from [10]

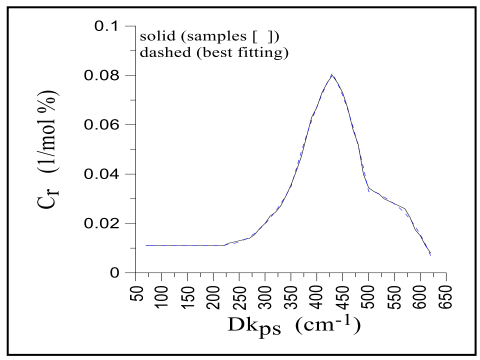



Fig. 4 values of $C_v$ [11]

The value of $g_{R0max}$ as a function of x is [12];

$$g_{Rxmax} = (1+8.0x)\, g_{R0max} \quad \text{(where x is a ratio)} \tag{11}$$

For silica, $g_{R0max}$ occurs at $\Delta k_{ps}$ = 420 cm$^{-1}$, therefore from Eq.8,

$$\lambda_{smax} = \left(\lambda_p^{-1} + 0.001\ \Delta kps\right)^{-1} \quad \mu m \tag{12}$$

* The temperature dependence of Raman scattering gain($g_{RxT}$) is derived from the relation between zero Kelvin Raman cross section of pure silica ($\sigma_0$) and temperature (T) which stated in [13]. The relation of $g_{RxT}$ is derived as;

$$g_{RxT} = g_{Rx}T_{p1} \tag{13}$$

Where, $Tp_1 = T_p / T_{p(T=300)}$ and $T_p$ is the thermal population factor [14,15];

$$T_p = 1 + \frac{1}{-1+\exp\{\ h\,(f_p - f_s)/T\, K_B\}} \tag{14.a}$$

Where; h is the plank's constant (h=6.625*10$^{-34}$ J.s), T is the temperature (T °K) and $K_B$ is the Boltzman constant ($K_B$ = 1.38*10$^{-23}$ J/°K), To=300°K and $f_p$ and $f_s$ are the pump and signal frequencies. So, the value of $h(f_p-f_s) / T\ K_B$ = 1.44 $\Delta k_{ps}$ /T

$$T_{p1} = \frac{[\exp(q_T+q_{To}) - \exp(q_T)]}{[\exp(q_T+q_{To}) - \exp(q_{To})]} \quad : \quad q_T = 1.44\ \Delta k_{ps}/T \quad , \quad q_{To} = 1.44\ \Delta k_{ps}/T_o \tag{14.b}$$

The temperature dependence of $T_{p1}$ becomes little at higher values of $\Delta k_{ps}$. For T< 300°K, the value of $g_{RxT}$ becomes smaller than that $g_{RxT}$ (at T=300°K) and it increases with T. While for T > 300°K, the value of $g_{RxT}$ becomes greater than that $g_{RxT}$ (at T=300°K) and it increases with T.

For $T=T_o=300^oK$ , the value of $T_{p1}$ equals one.

The final effective stimulated Raman scattering gain coefficient ($g_{rxT}$) is defined as ;

$$g_{rxT} = 100 \ g_{RxT} / A_{eff} \qquad (W^{-1}\ km^{-1}) \tag{15}$$

where, gRxT (in $10^{-13}$ m/W) and $A_{eff}$ (in $\mu m^2$)

Effective fiber core area ($A_{eff}$) is defined as [16]

$$A_{eff} = \frac{1}{2}\left(A_s + A_p\right) = \frac{\pi}{2}\left(W_s^2 + W_p^2\right) \tag{16.a}$$

Where, $A_s$ is the effective cross section area of the optical fiber at signal wavelength ($\lambda_s$), $A_p$ is the effective cross section area of the fiber at optical pump wavelength ($\lambda_p$), $W_s$ is the effective core radius at signal wavelength and $W_p$ is the effective core radius at pump wavelength. $W_{s,\,p}$ is defined as [8];

$$W_{s\,,p} = 0.65 + \frac{1.619}{V_{s\,,p}^{1.5}} + \frac{2.879}{V_{s\,,p}^{6}} \tag{16.b}$$

Where $V_s$ and $V_p$ are the normalized frequencies of fiber at $\lambda_s$ and $\lambda_p$, respectively. the value of $V_{s,p}$ decreases with $\lambda_{s,p}$ {where, $V_{s,p}=(2\pi\ a /\lambda_{s,p})\ (n^2_1-n^2_s)^{0.5}$ [8] and a is the fiber core radius}.
The value of $A_{eff}$ increases with fiber core radius and so $g_{rxT}$ decreases with core radius as explained in [17].
Also $A_{eff}$ increases with $\lambda_s$ (with $\lambda_p$ constant) , therefore, $g_{rxT}$ is lowerd with $\lambda_s$

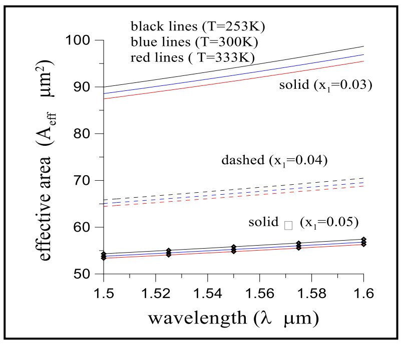



Fig.5 Effective optical fiber area versus wavelength λ

For pure silica, the maximum Raman scattering gain $g_{R0max}= 0.65*10^{-13}$m/W [18] which occurs at $\Delta k_{ps}$= 420 $cm^{-1}$ as shown in Fig.3.

*2.2 Effect of the amplifier length (L) on the amplifier gain (G)*

From Eq.3, and by putting dG/dL = 0, there is a peak value of gain ($G_{peak}$) at mean value of amplifier length ($L_{Gpeak}$ , it is called the optimum Raman amplifier length). . $L_{Gpeak}$ is derived as;

$$L_{G\,peak} = \ln(P_p\ g_{rxT}/\alpha_s) \ \ /\alpha_p \tag{17}$$

With $T=300^oK$ at x=0.03 the value of $L_{Gpeak}$ = 50 km.

**3. Results**

The simulation results is done for silica doped Germania Raman amplifier with the following data ; core radius (a=3.5 μm) , Germania ratio (x=0.03) , reference temperature ($T_o$=300 °K) , operating temperature (T=300 °K) , pump wavelength ($\lambda_p$=1.48μm) , pump power ($P_p$ =1W) , signal wavelength ($\lambda_s$=1527.55nm to 1567.19nm) , signal power at input of amplifier (Ps0 =0.1 mW i.e -10dbm) and the amplifier length (L =50 km , optimum Raman amplifier length) also with amplifier length (L=100 km).

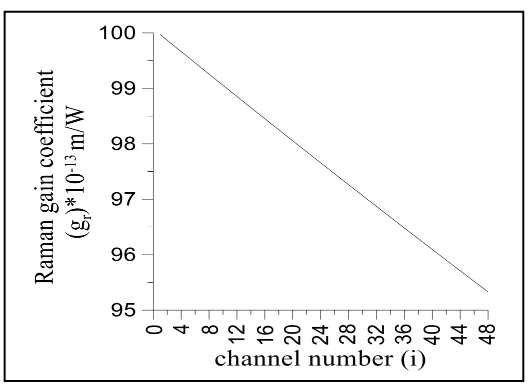
Raman amplifier is used to amplify a 48 WDM (with wavelengths of the center of the channel, $\lambda_{ch}$, are indicated in Table 1). The value of $\lambda_s$ is replaced by $\lambda_{ch}$ in the above equations (i.e. $\lambda_s=\lambda_{ch}$)

Table 1: Center wavelength ($\lambda_{ch}$)) of the 48 WDM, 100GHz (λ=1529.55 to 1567.19nm) [19]

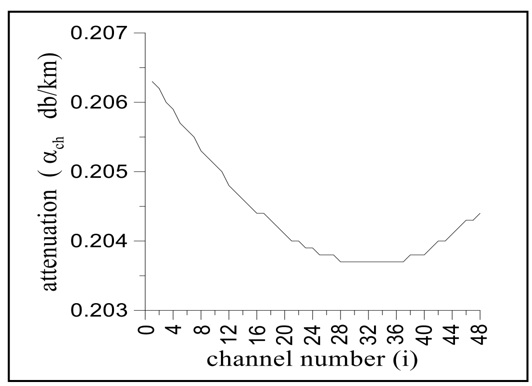
| channel | $\lambda_{ch}$ nm | channel | $\lambda_{ch}$ nm | channel | $\lambda_{ch}$ nm | channel | $\lambda_{ch}$ nm |
|---|---|---|---|---|---|---|---|
| 1 | 1529.940 | 13 | 1539.336 | 25 | 1548.732 | 37 | 155.8.128 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2 | 1530.723 | 14 | 1540.119 | 26 | 1549.515 | 38 | 155.8.911 |
| 3 | 1531.506 | 15 | 1540.902 | 27 | 1550.298 | 39 | 155.9.694 |
| 4 | 1532.289 | 16 | 1541.685 | 28 | 1551.081 | 40 | 156.0.477 |
| 5 | 1533.072 | 17 | 1542.468 | 29 | 1551.864 | 41 | 1561.260 |
| 6 | 1533.855 | 18 | 1543.251 | 30 | 1552.647 | 42 | 1562.043 |
| 7 | 1534.638 | 19 | 1544.034 | 31 | 1553.430 | 43 | 1562.826 |
| 8 | 1535.421 | 20 | 1544.817 | 32 | 1554.213 | 44 | 1563.609 |
| 9 | 1536.204 | 21 | 1545.600 | 33 | 1554.996 | 45 | 1564.392 |
| 10 | 1536.987 | 22 | 1546.383 | 34 | 1555.779 | 46 | 1565.175 |
| 11 | 1537.770 | 23 | 1547.166 | 35 | 1556.562 | 47 | 1565.958 |
| 12 | 1538.553 | 24 | 1547.949 | 36 | 1557.345 | 48 | 1566.741 |

The value of parameter ($g_{RxT}$) is decreased with $\lambda_{ch}$ (Fig.6.a). Also as expected $\alpha_{ch}$ decreases even $\lambda_{\alpha min}$ and it turned to increases for $\lambda_{ch} > \lambda_{\alpha min}$ (Fig.6.b)
The final out put gain (G) decreases with the center wavelength (through this bandwidth, 1527.55 to 1567.19nm) and gain lowered with increasing amplifier length (Fig.7)
The value of final gain with amplifier length equal the optimum Raman amplifier length ($L_{gpeak}$ =50km) is about 600 % of the gain with amplifier length 100km (Fig.7)
The final out put gain (G) decreases with the center wavelength (through this bandwidth, 1527.55 to 1567.19nm) and gain lowered with increasing amplifier length (Fig.7)

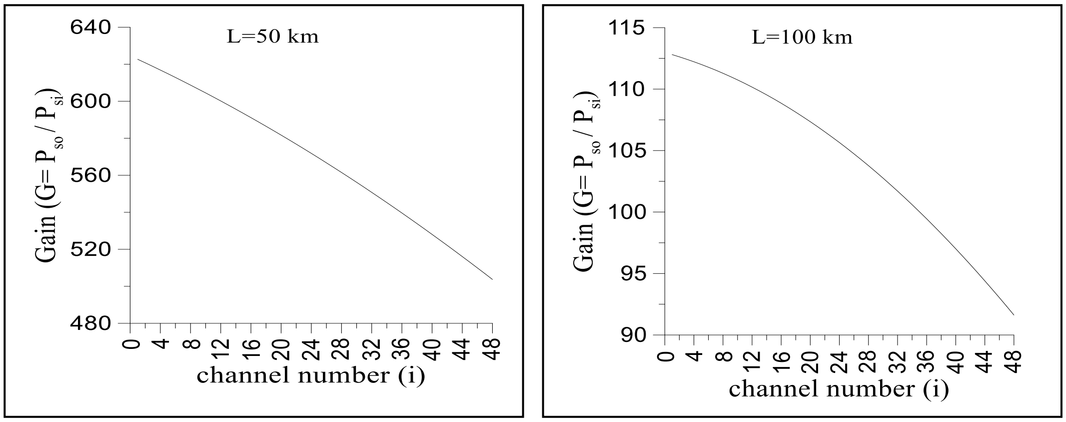



a) $g_{Rxt}$




b) $\alpha_{ch}$

Fig.6 Raman gain coefficient ($g_{Rxt}$) and attenuation coefficient ($\alpha_{ch}$) for each channel wavelength




a) L=50 km b) L=100 km

Fig.7 Variation of amplifier gain for each channel wavelength
Notice that L=50 km is the optimum Raman amplifier length ($L_{Gpeak}$)

Table 2 amplifier gain with L=50 km and L=100 km

| i | Gain L=50km | Gain L=100km | i | Gain L=50km | Gain L=100km | i | Gain L=50km | Gain L=100km | i | Gain L=50km | Gain L=100 km |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 622.67 | 112.81 | 13 | 597.95 | 109.85 | 25 | 569.29 | 105.20 | 37 | 536.78 | 98.86 |
| 2 | 620.76 | 112.62 | 14 | 595.71 | 109.53 | 26 | 566.73 | 104.74 | 38 | 533.90 | 98.25 |
| 3 | 618.83 | 112.43 | 15 | 593.44 | 109.20 | 27 | 564.14 | 104.26 | 39 | 530.98 | 97.64 |
| 4 | 616.86 | 112.23 | 16 | 591.15 | 108.85 | 28 | 561.52 | 103.77 | 40 | 528.06 | 97.01 |
| 5 | 614.87 | 112.01 | 17 | 588.83 | 108.49 | 29 | 558.88 | 103.27 | 41 | 525.10 | 96.38 |
| 6 | 612.85 | 111.78 | 18 | 586.48 | 108.12 | 30 | 556.21 | 102.76 | 42 | 522.13 | 95.73 |
| 7 | 610.80 | 111.54 | 19 | 584.11 | 107.74 | 31 | 553.51 | 102.24 | 43 | 519.11 | 95.07 |
| 8 | 608.73 | 111.29 | 20 | 581.71 | 107.35 | 32 | 550.79 | 101.70 | 44 | 516.08 | 94.40 |
| 9 | 606.63 | 111.02 | 21 | 579.28 | 106.94 | 33 | 548.04 | 101.16 | 45 | 513.03 | 93.72 |
| 10 | 604.47 | 110.75 | 22 | 576.82 | 106.53 | 34 | 545.27 | 100.60 | 46 | 509.95 | 93.03 |
| 11 | 602.34 | 110.46 | 23 | 574.34 | 106.10 | 35 | 542.46 | 100.03 | 47 | 506.84 | 92.33 |
| 12 | 600.16 | 110.16 | 24 | 571.83 | 105.66 | 36 | 539.63 | 99.45 | 48 | 503.71 | 91.62 |

## 4. Conclusion

The gain of Germania doped silica Raman amplifier fiber is affected by the optical fiber structure (core radius, a, ratio of Germania, x, and amplifier length, L) and the operating parameters (signal wavelength, $\lambda_s$, pump wavelength, $\lambda_p$, , pump power $P_p$, and temperature, T).

The final optical signal gain (G) independent upon the kind of pump. The final gain decreases with the channel wavelength ($\lambda_{ch}$). Maximum output gain occurs with coupler length equals the optimum Raman amplifier length ($L_{gpeak}$ , in this simulation results $L_{Gpeak}$=50km). the gain decreases with amplifier length.

The effect of $\lambda_s$ on the amplifier gain becomes very evident to degree there is variation of the channels gain. Gain of channel 1 greater than the gain of channel 48 by 19%.

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