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RESEARCH ARTICLE

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GAIN ANALYSIS OF DUAL PUMP FIBER OPTICAL PARAMETRIC AMPLIFIER

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ABSTRACT

Gain of dual pump parametric amplifiers has been analyzed with respect to different fiber parameters. It has been observed high gain is achievable of up to 51 dB using normal pump powers of less than 1 W over a wide bandwidth of more than 150 nm using dual pump parametric amplifiers. Careful optimization of dispersion parameters is required to achieve flat gain with gain ripple as low as 2 dB.

Keywords: Parametric amplification, dual pump, Highly Non-Linear Fiber(HNLF), Gain, Bandwidth.

INTRODUCTION

Parametric amplification in optical fibers was first observed this way by Stolen in 1975 [1]. In [2], Marhic et al. showed that by tuning λ_p near λ_0, it is also possible to obtain gain regions that are hundreds of nanometers wide, even with commonly available communication fibers, and reasonable pump powers (of the order of 1W) . Wong et al [3] reviewed the progress on FOPA emphasizing on its advantages- High Gain, large variety of gain spectra, large gain bandwidth upto 400 nm, tunable gain. [4] Theoretically investigated a multi-section OPA architecture that provides a nearly flat gain over a 100-nm bandwidth without any gain-equalization filter. [5] By suitably choosing the fiber properties and by tuning the pump wavelength near ZDWL, wide gain bandwidth can be achieved. Using single pump parametric amplification in HNLF, maximum on-off gain of 65 dB is achievable over 400nm bandwidth. In dispersion-shifted fibers, tunable gain regions less than 1 nm wide, up to 200 nm from the pump were achieved. [6]Effects of zero-dispersion wavelength (ZDWL) fluctuations on dual-pump fiber-optic parametric amplifiers were found to be highly non-uniform. Signal gain also varied considerably from fiber to fiber. Reducing the wavelength separation between the two pumps minimizes the effect of ZDWL fluctuations on gain but at cost of reduced amplifier bandwidth. [7]Gain of 29.2 dB with 0.63W of single pump using high repetition rate pulsed pump was achieved. [8]The demonstrated peak gain of 91.4dB in high nonlinear PCF with minimal effect of ZDWL fluctuations and low dispersion slope over a very wide spectral range. In [9], Mussot et al demonstrated PCF based continuous-wave all-fiber optical parametric amplifier in the 1 µm band with a record bandwidth of more than 20 THz with \peak gain of almost 40 dB. In [10] single pump FOPA was investigated for 8-channel WDM system. It was shown for low number of channels the dominant cause of performance degradation at high power levels is the nonlinear effects of the transmission fibers rather than the nonlinear cross-talk due to the FOPA. But for large number of WDM channels the nonlinear cross-talk due to the FOPA is the dominant cause of performance degradation at large power levels. Use of dual-pump FOPA for generation of uniform pulses [11] with duty cycle of 0.265 and 5 Ghz pulse repetition rate over 40 nm bandwidth by bounding the phase mismatch between $-3\gamma P_0$ and γP_0 to achieve a constant peak gain was demonstrated. PCF-based optical parametric amplifier [12] pumped by a homemade mode-locked ytterbium doped fiber laser was demonstrated to give maximum parametric gain of 58 dB from 999 nm to 1139 nm when pumped near the zero dispersion wavelength. The dispersion and nonlinear properties of the PCF are exploited to fulfill the phase matching condition for four wave mixing (FWM).

Theoretical Model: Fiber-optic parametric amplifiers (FOPAs) employ the nonlinear phenomenon of four wave mixing (FWM) to transfer energy from one or two strong pump fields to weak signal fields. Since then, FOPAs have proved to be a versatile for important applications [13], [14].

FWM is governed by:

$$\omega_4 = \omega_1 + \omega_2 - \omega_3 \quad (1)$$

Where, ω_1, ω_2, ω_3 and ω_4 are two pump frequencies, signal frequency and the idler frequency.

For length 'L' of HNLF used for parametric amplification gain of signal is expressed as:

$$G(\omega_3) = \left[1 + \left(1 + {K^2}/{4g^2}\right) sinh^2(gL)\right] \quad (2)$$

Where, $g^2 = 4\gamma^2 P_1 P_2 - \left(\frac{K}{2}\right)^2$ for 'γ' as non-linear coefficient and P_1, P_2 are pump wavelengths.

RESULTS AND DISCUSSIONS

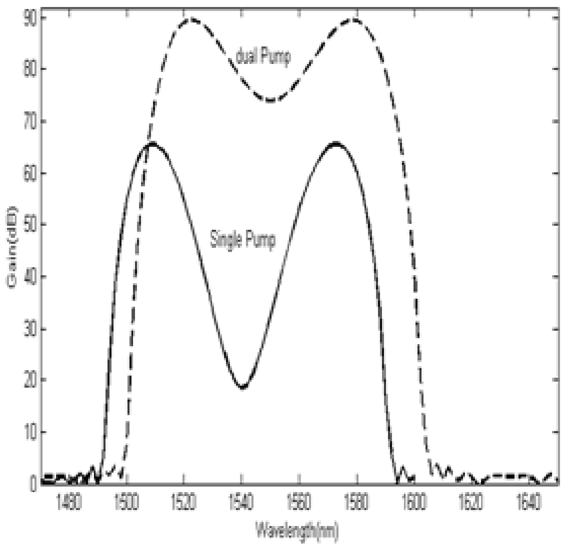

Figure 1 Single pump vs dual pump gain variation for pump powers of 1W in 100m of HNLF, γ=10$W^{-1}Km^{-1}$, β_2=-2.2X10^{-2} ps^2/km^2,β_4=1.34X10^{-4} ps^4/km^4,λ_0= 1550 nm,λp=1540.2 nm (single pump) and λ_1= 1540.2nm and λ_2= 1560 nm(dual pump)

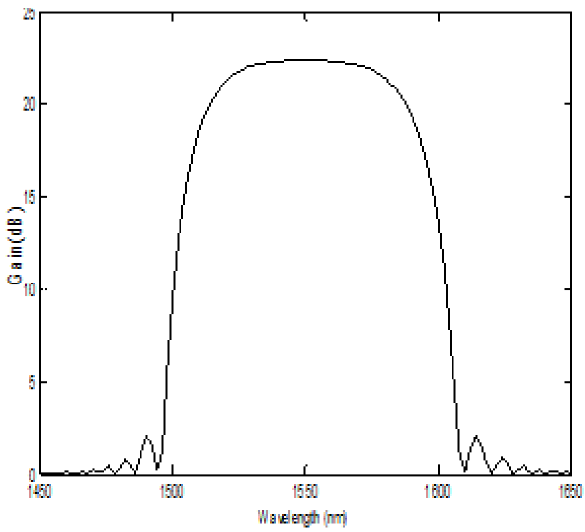

Figure 2 Gain curve of dual-pump single-section FOPA with γ=18 W-1km-1, λ_0=1550 nm, λp_1=1540 nm, λp_2=1560 nm,P1=P2=1 W, L=0.1 km, β_3=0.12 $ps^3km^{-1}$and β^4=2.5X10^{-4} ps^4km^{-1}.

Compared with that of single-pump FOPA, the gain flatness of dual-pump FOPA is considerably improved [14] as is seen in figure 1.

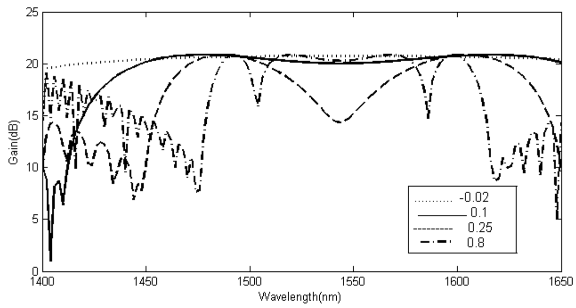

Figure 3 At constant β_4 =10^{-4} variation of gain with β_3 using HNLF with attn=0.8db/km and L=500m with λ_1=1495 and λ_2=1570,γ=17.

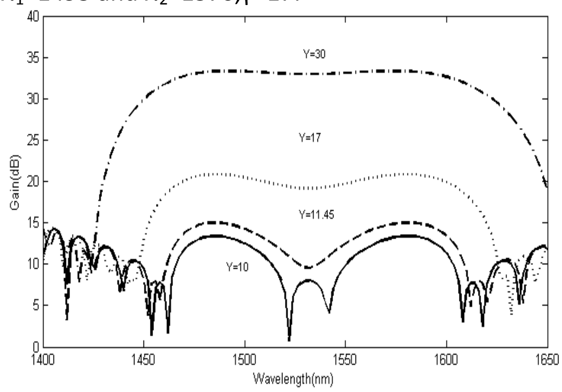

Figure 4 Variation of dual pump FOPA at P_1=P_2=0.25W, β_3=0.1, β_4=10^{-4} ps/nm^4/km using HNLF with α=0.8 dB/km and L=500m with λ_1=1495 and λ_2=1570

As seen value of β_4 has little effect on gain and is mainly dominated by second order dispersion parameter.

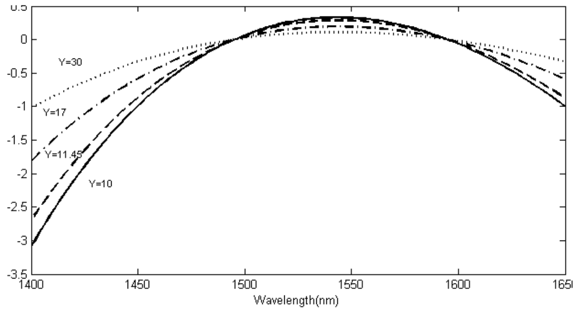

Figure 5 Variation of r= $\Delta\beta/\gamma(P_1+P_2)$ at different values of γ, $P_1=P_2=0.25W$, $\beta_3=0.1$, $\beta_4=10^{-4}$ ps/nm^4/km using HNLF with α=0.8 dB/km and L=500m with $\lambda_1=1495$ and $\lambda_2=1570$

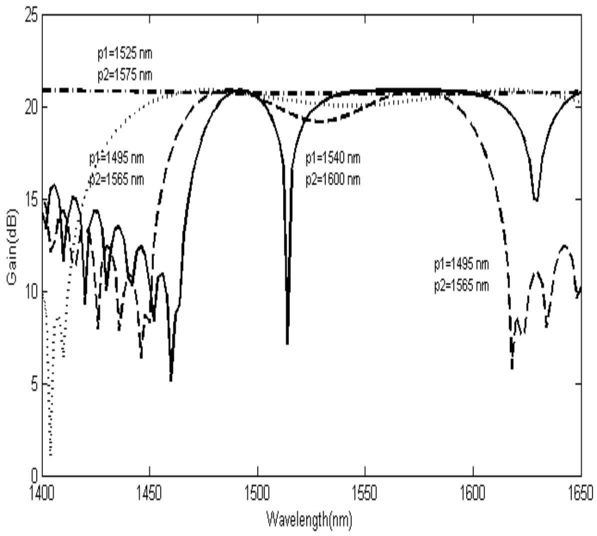

Figure 6 Variation of dual pump gain with different values of pump wavelengths $P_1=P_2=0.25W$, $\beta_3=0.1$, $\beta_4=10^{-4}$ ps/nm^4/km using HNLF with α=0.8 dB/km and L=500m

When pump wavelengths are detuned at $\lambda_1=1495$ and $\lambda_2=1595$, maximum gain achieved is 2 20.8428 dB, while dip in gain is reduces gain to minimum 20.01702dBat 1544 nm. For asymmetrical pump detuning towards the ZDWL, at $\lambda_1=1495$ and $\lambda_2=1565$ maximum gain starts reducing to 20.8422 dB over 88nm flat gain bandwidth from 1486 nm to 1574 nm while gain dip deepens to 19.1547 dB. For symmetrical pump wavelength tuning $\lambda_1=1525$ and $\lambda_2=1575$ maximum gain is 20.8428 while minimum gain in flat gain bandwidth is 20.670. Further tuning of pumps wavelengths closer to ZDWL, $\lambda_1=1540$ and $\lambda_2=1600$ gain is stable at 20.8428 dB.

As observed from figure 7 as length of HNLF used for parametric amplification is increased gain increases. With fiber length 'L' = 200 m maximum gain is 10.24 dB over 102 nm bandwidth from 1480 nm to 1582 nm while gain dips to 4.677dB at 1530nm. For increase in fiber length to 500 m maximum gain increases to 15.0058 dB with gain bandwidth of 90 nm from 1486 nm to and gain dip occurs at 1530 nm with gain =9.7798 dB. But as we increase fiber length from few meters to 'kilometers' increase in gain starts getting saturated and beyond fiber length of 10km no significant increase in gain occurs.

HNLF used for parametric amplification have attenuation higher than single mode fibers. The effect of gain variation with attenuation in dual pump parametric amplifiers is shown in figure 8. For HNLF the attenuation varies between 0.3 to 1 dB/km. But value of attenuation is generally kept high around 0.8dB/km. As the attenuation increases the gain decreases For shorter lengths attenuation effect is negligible both for dual pump as well as single pump parametric amplifiers as length of fiber used is small ~ 100m. In case of PCFs fiber length used is small as 50 m because highly non-linear characteristics of PCF give high gain to signal along with idlers. For this reason effect of attenuation is generally ignored by considering only actual length of fiber.

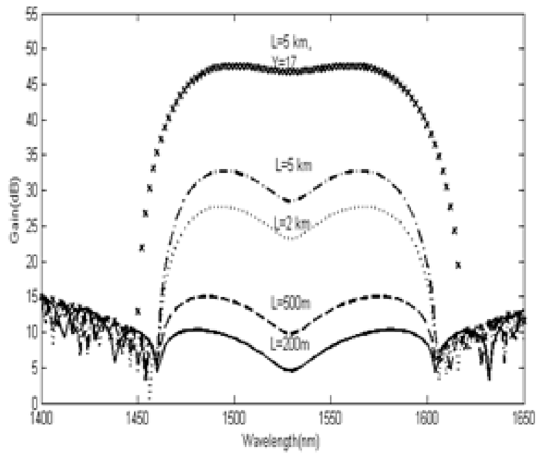

Figure 7 Variation gain at different values of fiber length 'L' at $P_1=P_2=0.25W$, $\lambda_1=1545$ nm and $\lambda_2=1565$ and γ=11.45

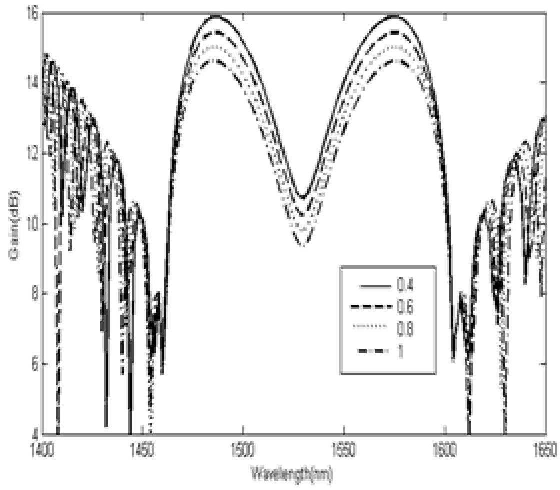

Figure 8 Variation gain at different values of attenuation (α) at $P_1=P_2=0.25$W, using HNLF L=500m with $\lambda_1=1495$ and $\lambda_2=1565$ and γ=11.45

Conclusion

We have analyzed the performance of dual pump parametric amplifiers with respect to different fiber parameters. Results show careful optimization of HNLF parameters leads to flat gain parametric amplification over wide bandwidth with gains as high at 51 dB with normal pump powers of less than 1 W. This is important for design of wideband high gain tunable amplifiers required for evolving broadband communication systems.

REFERENCES

[1]. Stolen, R. H. (1975), *Phase-matched-stimulated four-photon mixing in silica fiber waveguides,* IEEE Journal of Quantum Electronics,Vol. 11, pp. 100-103.

[2]. Marhic, M. E. et al (1996), *Broadband fiber optical parametric amplifiers*, Optics Letters, Vol. 21, No. 8, pp 573-575.

[3]. Wong et al (2005), *Recent Advances in the Design and Experimental Implementation of Fiber Optical Parametric Amplifiers*, IEEE Conference on Optoelectronic and Microelectronic Materials and Devices, pp 409-412.

[4]. Provino, L. et al (2002), *Broadband and flat parametric gain with a single low-power pump in a multi-section fiber arrangement*

[5]. Marhic, M. E.et al (2004), *Wideband tuning of the gain spectra of one-pump fiber optical parametric amplifiers*, IEEE Journal of Selected Topics in Quantum Electron,Vol.10, No. 5, pp.1133-1143.

[6]. Yaman, F. et al (2004), *Impact of Fiber dispersion fluctuations on Dual-pump Fiber Optical Parametric Amplifiers*, IEEE Photonics Technology Letters, Vol. 16, No.5, pp1292-1295.

[7]. Georgois, K. et al (2006), *High-repetition rate pulsed-pump Fiber OPA for amplification of communication Signals*, IEEE Journal of Lightwave Technology, 2006, Vol. 24, No. 8, pp 3021-3028.

[8]. Shang, Tao et al (2009), *Numerical analysis of fiber optical parameter amplifier based on triangular photonic crystal fiber*, SCI China series F: Info Sciences, Vol. 52, No.7, pp 1272-1278.

[9]. Mussot, A. et al (2012), *20 THz-bandwidth continuous-wave fiber optical parametric amplifier operating at 1 μm using a dispersion-stabilized photonic crystal fiber*, Optics Express, Vol. 20 ,No.27, pp 28906-28912.

[10]. Jazayerifar, M. et al (2013), *Performance Evaluation of DWDM Communication Systems With Fiber Optical Parametric Amplifiers* IEEE Journal of Lightwave Technology, Vol. 31, No. 5, pp 1454-1462.

[11]. Shoaie M.A. et al (2014), *Wideband generation of pulses in dual-pump optical parametric amplifier: Theory and Experiment*, Optics Express, Vol.22, No.40, pp 4606- 4620.

[12]. Zhang, Lei et al (2014), *Photonic Crystal Fiber Based Wavelength-Tunable Optical Parametric Amplifier and Pico-second Pulse Generation*, IEEE Photonics Journal, Vol. 6, No. 5, *open access.*

[13]. Agrawal, G. P. (2002), *Fiber-optic Communication Systems*, Wiley New York.

[14]. Torounidis, T. et al (2006), *Fiber-optical parametric amplifier with 70-dB gain*, IEEE Photonics Technology Letters, Vol. 18, No.10, pp 1194-1196.