Investigation on Fiber Optical Parametric Amplifier (FOPA) Bandwidth using Optisystem

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Abstract— This study discusses about single-pump Fiber Optical Parametric Amplifier (FOPA) bandwidth based on Four-wave Mixing (FWM). The wider bandwidth of the gain spectrum of FOPA is one of promising feature nowadays. We has simulates the FOPA in the Optisystem software and analyze the effects of dispersion, dispersion slope and effective area to the bandwidth. The bandwidth is varies as we varies the value of parameter mention before and the widest bandwidth recorded by is 100 nm.

Keywords— Four-Wave Mixing; Fiber Optic Parametric Amplifier; Zero-Dispersion Wavelength.

1. INTRODUCTION

Four-wave mixing (FWM) occurs when a light of two or more with different wavelength have been launched into the fiber [1]. Figure 1 shows the phenomenon of FWM. When the lights have been launched, new waves will be raised that known as an idler. Idler also has a different wavelength compared to the light that have been launched in the fiber [2]. The operation system in the zero dispersion wavelength is one of the aspect to realize the high speed delivery in order to prevent the degradation that cause by chromatic dispersion [3]. Fiber optical parametric amplifier (FOPA) is one of the FWM application. FOPA is widely used in order to obtain high gain and large bandwidth [4]. FOPA have the potential in providing wider bandwidth either one or two pumps [5]. FOPA play a vital role for future fiber optical amplifiers because of their high gains, broad gain bandwidth and relatively low noise figure [6]. The highest gain achieve by the FOPA is 70dB [7]. In order to obtain the wide gain, it is essential to having the higher nonlinearity of the optical fiber itself. This is the reason why we were choosing the highly nonlinear fiber (HNLF) in this study. The combination of parametric gain and Raman have provided a 200nm bandwidth [8]. The FOPA bandwidth recently has been analyzed using cascaded structure with 80 nm bandwidth achieved [9]. Other than that, the cascaded FOPA is having the optical bandpass filter between two fiber in order to obtain high gain and wider bandwidth [10]. The single pump FOPA has been chosen because of the less complexity and low cost. In this study, we demonstrate the FOPA using HNLF in Optisystem software. The parameter like dispersion, dispersion slope and effective area are varies in order to see the changes in bandwidth.

2. THEORY

Four-wave mixing (FWM) is third-order nonlinearity in optical fiber. When the wavelength channels are located near the zero-dispersion wavelength, the new idler light will arise with the same spacing between the pump and signal between the pump light.

$$f_{\text{idler}} = f_{\text{pump}_1} + f_{pump_2} - f_{\text{signal}} \tag{1}$$

These idler will travel along with the original waves and will grow at the expense of the signal-strength depletion. The pump light must near the zero-dispersion wavelength in order to achieve phase-matching condition. The idler power decreases as the channel spacing become is widen, due to high group velocity mismatch.

$$P_{\text{idler}}(L) = \eta(\mathcal{D}\kappa)^2 P_{\text{pump}}(0) P_{\text{signal}}(0)\exp(-\alpha L), \tag{2}$$

where L is the length of the fiber, α is the attenuation of the fiber, η is the efficiency of the four-wave mixing and $\mathcal{D}$ is the degeneracy factor, which has the value of 3 or 6 for two waves mixing or three waves mixing, respectively. The nonlinear interaction constant κ is

$$\kappa = \frac{32\pi^3\chi_{1111}}{cn_2\lambda}\left(\frac{L_{eff}}{A_{eff}}\right) \tag{3}$$

where χ_{1111} is the third nonlinear susceptibility, n_2 is the refractive index of the fiber, L_{eff} is the effective length of the fiber and A_{eff} is the effective cross-sectional area of the fiber. The nonlinear coefficient γ is

$$\gamma = \frac{2\pi n_2}{\lambda A_{eff}} \quad . \tag{4}$$

The phase matching Δκ depends on the fiber dispersion, channel spacing and the fiber length [11]. The equation is given as follow

$$\Delta k = \frac{2\pi\lambda^2{}_k}{c}\Delta f_{ik}\Delta f_{jk}\left[D_c + \frac{\lambda^2{}_k}{2c}\left(\Delta f_{ik} + \Delta f_{jk}\right)\frac{dD_c(\lambda_k)}{d\lambda}\right] \tag{5}$$

where $\Delta f_{ik} = |f_i - f_k|$ is the channel spacing, D_c is the fiber dispersion, $\frac{dD_c}{d\lambda}$ is the dispersion slope and λ_k is the wavelength corresponding to the wave at frequency f_k.

3. FWM SYSTEM

The simulation setup is shown in Figure 2. The continuous wave (CW) pump is used because of the gain saturation can be reached for low signal input power [12]. The pump wavelength is 1542 nm. The signal laser wavelength is tuned in range 1450 - 1650 nm. The pump laser power is 36 dBm and for the signal laser at -36 dBm. The polarization controller is used in the simulation model in order to keep the polarization between the pump and signal laser coincides. Five RF frequencies at 105MHz, 325MHz, 1000MHz, 3150MHz and 10GHz will connected to the phase modulator in order to suppress the stimulated Brillouin scattering (SBS) [13]. The zero dispersion wavelength is set at 1541 nm. When $\lambda_p - \lambda_0 = 1$ nm , the gain bandwidth is believed to be large [14].

The dispersion and the dispersion slope are set at value near zero so that phase matching can easily happen. The value is vary in order to observe the changes of the bandwidth enlargement. The dispersion parameter is varied from 0.5 to 1 ps/nm^2/km. While, the dispersion slope is varied from 1 to 0 ps/nm^2/km. The FWM process becomes significance when the fiber dispersion is small.

Subsequently, the effective area of the fiber core is varied. This is because the efficiency of the FWM is also depends on the effective area. The effective area is varied from 10.7, 11.6 and 21μm^2. By varying the effective area, the nonlinear coefficient is varied. As stated in (4), small effective area provide high nonlinear coefficient. The length of the highly nonlinear fiber (HNLF) is 0.20 km with the attenuation is 0.2 dB/km. The output spectrum is observed by using optical spectrum analyser (OSA).

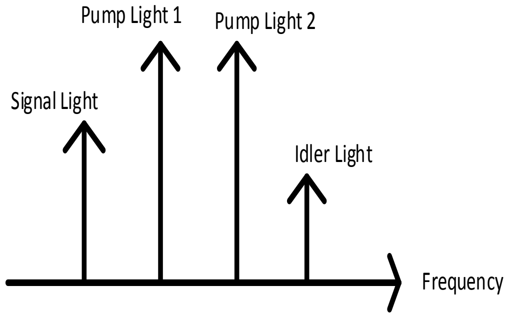

Figure 1: FWM phenomenon in optical fiber

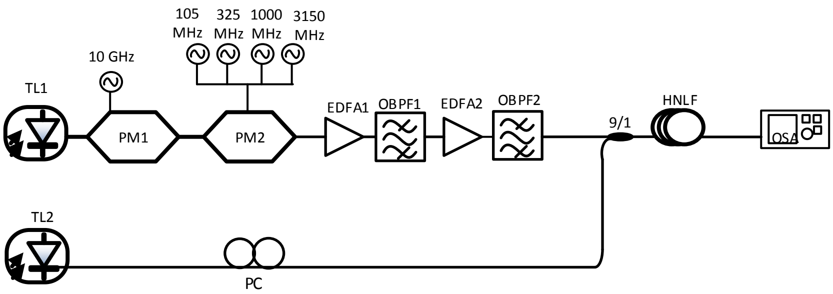

Figure 2: The simulation model in Optiwave Software

4. RESULT AND DISCUSSION

The output in optical spectrum analyzer shows the spectrum arise in the optical fiber. The idler arise along the fiber. The interaction of the pumps and signal light that produce an idler has been satisfied in this investigation. Figure 3 shown the idlers arise at the same spacing between each other.

The gain graph has been observed in order to see the bandwidth enlargement. Firstly, we observed through vary the dispersion. Figure 4 indicate the bandwidth enlargement when the dispersion was varied from 0 to 1 ps/nm/km. The other parameters remain unchanged. FOPAs have a wider bandwidth of the gain spectrum because of the phase-matching condition.

The dispersion slope value also has been varied. The value of dispersion slope was changed to 0, 0.031, and 0.5 ps/nm^2/km. As shown in Figure 5, it clearly specified the FWM gain when exchanging the dispersion slope. The smaller the value of the dispersion slope will provide the smaller value of phase matching. As we know, the value of phase matching is advised to be near zero. As we saw in the figure, the bandwidth of 0 dispersion slope is broader compare to the dispersion slope 1.

The dispersion and dispersion slope is related to each other in term of phase matching condition. This is why the smaller value of the dispersion and dispersion slope will provide the wider bandwidth of the gain spectrum.

As mention before, the effective area of the fiber also play an important role towards the enlargement of the gain bandwidth. By having the smaller value of the effective area will provide the higher nonlinearity to the optical fiber. The gain of the smaller effective area is not only has a wider bandwidth; it also has higher gain compare to the larger effective area. As we know, the smaller core size of HNLF is necessary to suppress the SBS that generated by the pump light of FOPA [15]. In Optisystem software, we can change the nonlinearity of the fiber by changing the value of effective area. Figure 6 clarifies the enlargement of the bandwidth when the effective area of the fiber becomes smaller.

5. CONCLUSION

In conclusion, the magnitude of fiber dispersion, dispersion slope and effective area effect FWM bandwidth. By optimizing the parameters, the bandwidth of the FWM is enlarged up to 100 nm in this study. The dispersion and dispersion slope value near to zero result in a large FWM bandwith. While for the effective area, a smaller of it will provide a larger bandwidth.

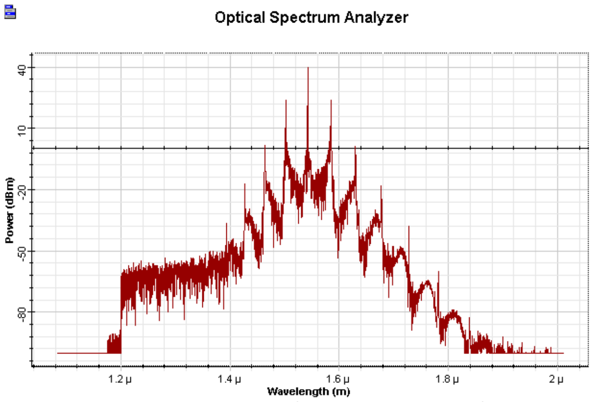

Figure 3 : Spectrum of FWM in the optical fiber

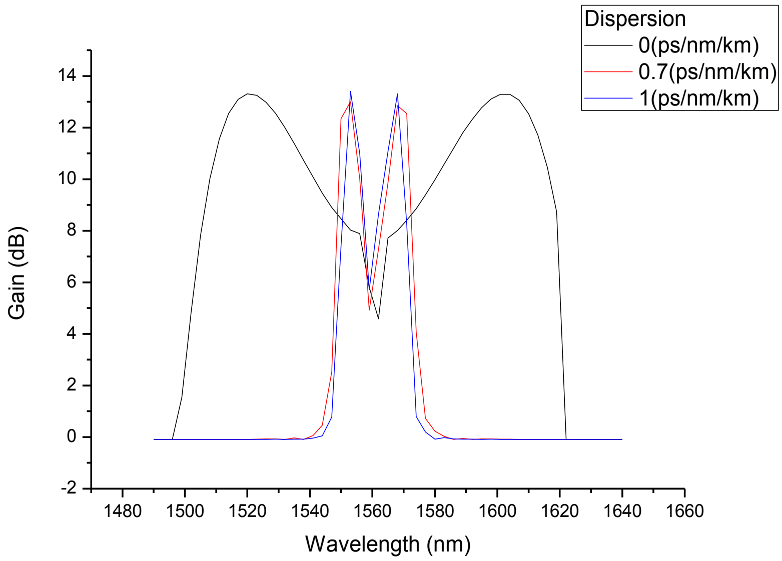

Figure 4 : The gain bandwidth graph for varying the dispersion of the optical fiber

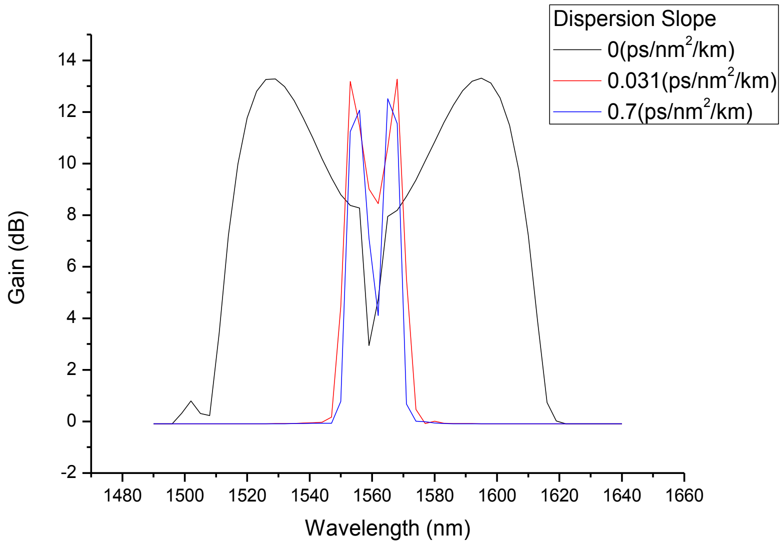

Figure 5 : The gain bandwidth graph for varying the dispersion slope of the optical fiber

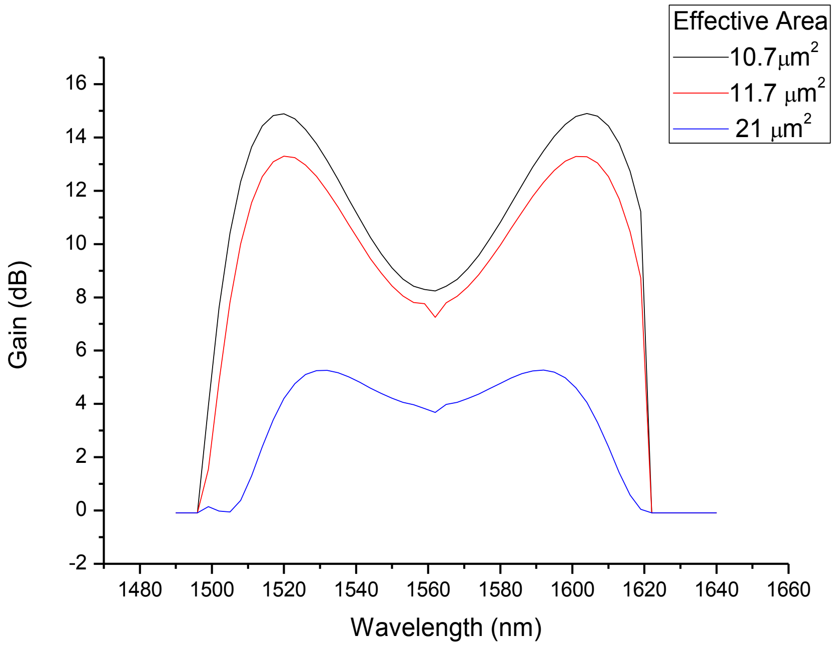

Figure 6 : The gain bandwidth graph for varying the effective area of the optical fiber

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