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Four Wave Mixing Signals Generation at 25 dBm High Power EDFA

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Abstract: A four wave mixing (FWM) signal generation based on few mode fiber laser (FMF) has been demonstrated using a high power Erbium Doped Fiber Amplifier (EDFA) in a linear cavity. The proposed cavity can generate the highest peaks of four wave mixing signals at wavelength of 1550 nm and 1551 nm at a given of 25 dBm input power from EDFA with output peaks power of -2.55 dBm and -6.43 dBm were generated respectively. The lowest Optical Signal to Noise Ratio (OSNR) for the peak probe was recorded at 50 dB that negates minor fluctuations in cavity. The idlers were obtained at 9.1 dB and 4.4 dB OSNR at 1549.1 nm and 1552.4 nm respectively. It is expected that this laser cavity will be an alternative platform to develop bio-sensor by utilizing nonlinear properties of photon in order to meet the increasing demand in medical study.

Keyword: Four Wave Mixing; Two mode fiber ; EDFA; Bio-sensor.

1. Introduction

In the mean of expanding the capacity of data transmission, the ability of nonlinear effects has been recently examined. Nonlinear effect in optical fibre is referring to the effect that acts as a hindrance of pulse propagation due to the change of refractive index with optical power and energy field [1]. Four wave mixing (FWM) is one of the nonlinear effects and the formation of this effect was first discovered in few mode fiber (FMF) in 2003 [2]. FWM occurs when more than one light with different wavelengths are launched into a same optical fiber and generating two or more new waves with different wavelengths, which ~~is~~ known as idler. FMF has become one of a great attraction in optical fiber sensor and biosensor as this type of fiber provides advantages of low loss, polarization insensitivity, high reliability, and compatibility to the transmission line [3]. FMF are now widely used in optical switch system [4], bio-sensor [5], wavelength converter [6] and mode converter [7]. Bio-sensor is an analytic device to detect analyte by altering a biological response into electrical pulse or signal [8]. FMF with resonance response was discovered for prostate antigen in 2009 [9]. Other than that, spectral shift of the peak measurement of FWM was utilized in biosensor field in a designed experiment in 2011 to detect aqueous solution based on refractive index [10]. In 2017, a proposed novel temperature sensor based on modulational instability (MI) was discovered utilizing FWM approach [11]. Deviation of zero dispersion wavelength along the optical fiber length plays vital role in developing of FWM [12]. Phase match effect is another crucial factor to drop down efficiency of FWM [13]. In this paper, a linear fiber laser cavity is used to perform FWM in FMF. This method has been used to perform multi-point temperature sensing in 2017 [14]. Formation of FWM in FMF had been carried out with high stability as two different waves of light source are launched into the system.

2. Theory

Launching two input signals in a same optical fiber theoretically will generate FWM. FWM is also a parametric interaction among waves satisfying phase matching. It is a process of energy conversion taken by the photon pairing in a high irradiance beam upon scattering off the host material. As the process excludes material resonances, total photon energy is necessary to be preserved for significant FWM gain. The induced power transfer from the main pump beam to such satellite spectral sidebands of FWM comes into limitation when it emerges in pulse fiber laser and pulse fiber amplifier

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meant to retain high spectral brightness. Another necessary condition for efficient FWM is the total photon momentum be preserved, which is known as the phase matching condition and is quantified as in Equation 1,

$$\Delta k = 2\emptyset_0 - \emptyset_1 + \emptyset_2 = 0 \qquad (1)$$

where phase shift, $\emptyset_i \ \ and\ i = 0,1,2$ is defined based on Equation 2.

$$\emptyset_i = \frac{2\pi n_{eff}(\lambda_i)}{\lambda_i} + \emptyset_{NL(i)} \qquad (2)$$

Here the symbols of Δk, λ_i, $n_{eff}(\lambda_i)$ and $\emptyset_{NL(i)}$ indicates the phase shift, wavelength, fiber refractive index and non-linear phase shift for each beam respectively. As mentioned by Liu et.al [15], FWM effect in the cavity is related to three parameters of optical fiber; the length, the dispersion and the nonlinearity coefficient. Phase matching is a group of applied technique to generate efficient nonlinear interactions in a medium. It is ensuring that a proper phase relationship between the interacting waves is maintained along the propagation direction in an optical transmission system [16].

3. Experimental Setup

Fig. 1 shows the experimental setup for FWM signals in FMF. Light sources were from two different tunable laser source (TLS) system. This experiment was set up at wavelengths of 1550 nm and 1551 nm. The output optical power readings were collected by optical power meter. A safety precaution was emphasized as optical input should be controlled to avoid any critical effects on the sensitive OSA such as inter core burning inside the fiber connector like pigtail. The light wave propagation was started from both of TLS. Two identical light waves with different wavelengths of 1550 nm and 1551 nm were launched into a 2x1 3 dB coupler from two TLS before they were amplified by HPEDFA. The HPEDFA is an active gain media which amplifies the power of light waves that propagate through. The light waves propagated in unidirectional path as the insertion of an isolator before the under test fiber (UTF). In this experiment the UTF was FMF. The light waves were expected to generate nonlinear effects through these FMF. The FMF insertion was identified performing a better stability of FWM effects in the circuit. The formation of FWM suffered with greater fluctuation of peak power and less stable without the FMF in a cavity. After the propagation through FMF, the light waves split at the 90/10 optical coupler output ports. Only 10 % of the total optical power output from the propagated light waves directed to the optical spectrum analyser to read and display the optical spectrum of the expected four-wave mixing effects in optical fiber. The rest of 90% of the optical power had ended at the end connection.

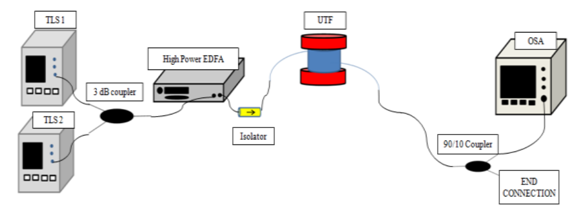

Fig. 1 The experimental setup for FWM in Under Test Fiber (UTF).

4. Result and Discussion

Fig. 2 shows the optical spectrum of FWM as a given 25 dBm of EDFA output power was launched into the laser system to generate FWM. There are four peaks of different wavelengths are obtained in the result. Two of them are belong to the pump and probe while another two are known as idlers. The two idlers are from the interference of two input wavelengths with the presence of nonlinear response in optical fiber. The power for the first probe peak is -2.55 dBm while the second probe peak power is -6.43 dBm. The shorter wavelength idler is -48.9 dBm of peak power and the longer wavelength idler peak power is -52.6 dBm. The OSNR values had shown in the Fig. 2 and are labelled to each of the peak. The OSNR of the idler 1, pump peak, probe peak, and idler 2 are 9.1 dB, 54.45 dB, 50.57 dB, and 4.4 dB respectively.

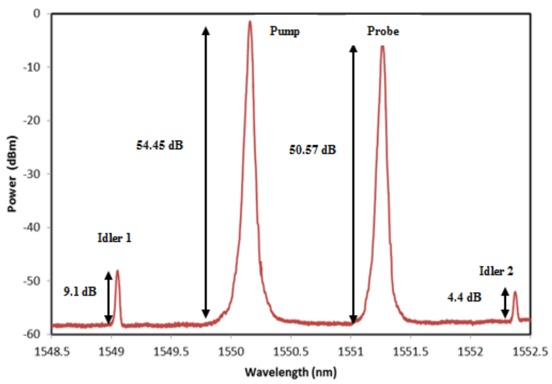

Fig. 2 The FWM spectra in FMF.

The plot in Fig. 3 shows the optical power obtained from the peak power reading which a respond to the inclination of pumping output power given from the EDFA at a fixed of both TLS wavelengths. The threshold pumping power to generate the four wave mixing based on this circuit configuration is 23.7 dBm. The result is obtained from the OSA. The current injection is increased to obtain the respond for the four-wave mixing effect in 2MF. The pumping power is varied from 22 to 27.7 dBm. The peak pump power is increased from -3.345 dBm at 22 dBm to 0.429 dBm at 27.7 dBm. This significance of 3.77 dB power differences for a 5.7 dBm increasing power value is able to be utilized for communication system as it is more than 50% of power inclination. The peak power for probe is lower than the peak power of pumping as the pumping is obtained from EDFA with current injection. The peak of probe shows an increase in value as the applied current is increased. At 22 dBm the peak probe power is -12.113 dBm which is the lowest and the highest power is recorded at 27.7 dBm which is -6.749 dBm. The power different is 5.36 dB. Peak power probe is slightly higher than the pump peak power as peak power probe is originated from the light source. The idler peak power is also increased in value in respond to the higher current value given to the EDFA. At 22 dBm, the peak power of idler is -59.179 dBm while at the 27.7 dBm the peak power is -48.187 dBm. Thus, lead to the power difference of 10.99 dB between both peaks. The background noise is also recorded about -61.073 dBm at 22 dBm and increased up to -55.804 dBm at 27.7 dBm. It is an increment of 5.27 dB.

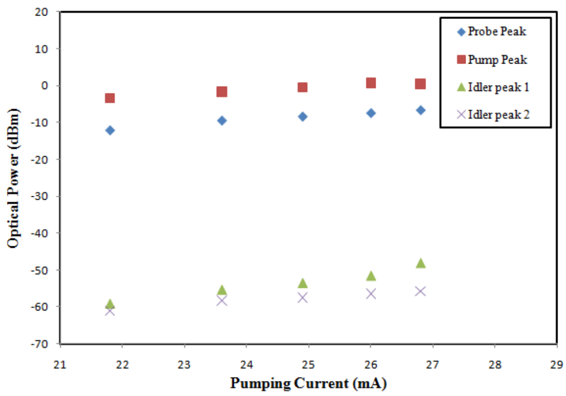

Fig. 3 Peak power readings.

Fig. 4 shows the power difference over a varied output power of EDFA for the value of side mode suppression ratio (SMSR) and optical signal-to-noise ratio (OSNR). The highest pump peak for each current supplied is recorded and compared to the noise which had been measured from the graph of the optical spectrum analyzer. The OSNR is reduced from 57.73 dB to 56.23 dB at 22 dBm and 27 dBm respectively. The SMSR produced a greater reduction which is 7.22 dB as compared to the OSNR which is 1.5 dB due to the increase of secondary idler peak power and the increase of noise as the current is increased. The noise was affected by the high amplified spontaneous emission from EDFA as input power given to the cavity has been increased.

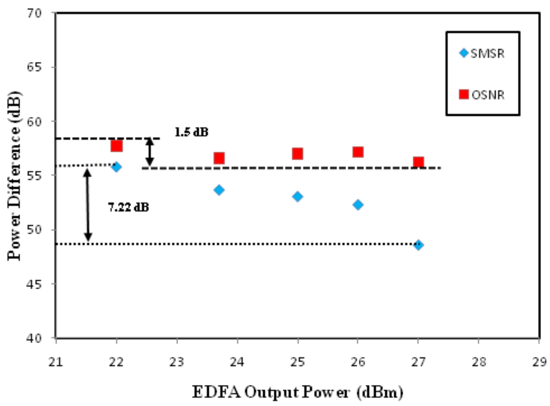

Fig. 4 SMSR and OSNR readings.

Fig. 5 shows the comparison of the EDFA output power changes over two different OSNR produced from two idlers. The first idler is independent to the increasing of output power given but the second idler gives an increment profile. The second idler is directly influence to the SMSR between peak one and peak two. The secondary peak value is directly proportional to the output power from EDFA. Thus the FWM for this configuration of circuit is depending on the input power of EDFA.

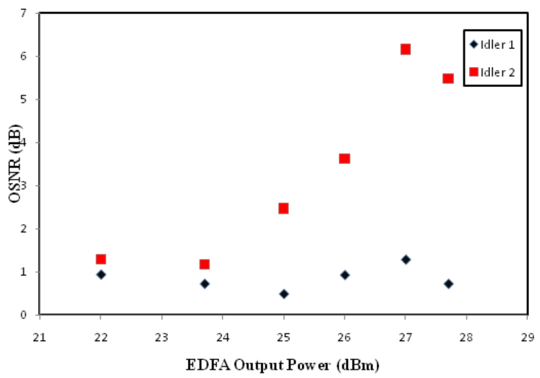

Fig. 5 OSNR readings for idlers.

5. Conclusion

The FWM in FMF was successfully performed at 1550 nm and 1551 nm input wavelengths from two units of TLS at 25 dBm output power from EDFA. There are room of improvements as this non complex system ignores the generation of scattering phenomena such as Brillouin and Raman in the cavity. However, this result can be a brief reference to generate more complex and flexible wavelength application such as wavelength converter especially by utilizing FMF and erbium doped fiber amplifier as a gain medium in any type of laser cavity. It is recommended for the other researcher to suppress the Brillouin scattering effect maximally in optical fiber to enhance the FWM effect and develop a higher SNR and at the same time a stable and high power idlers can be developed. In the future, a simple and flexible optical switching based on nonlinear effects may be utilized widely in larger scope to support super speed data transmission in optical communication system especially in the form of mode conversion and wavelength conversion.

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