Journal of Science and Technology, Vol. 10 No. 4 (2018) p. 33-36

The Influence of Nonlinearity Properties in Generating Octave-spanning Light

Mofaq M.B. Alsaady, N.A. Awang* and Z. Zakaria

Optical Fiber Laser Technology (OpFLAT) Focus Group, Department of Physics and Chemistry, Faculty of Applied Science and Technology, University Tun Hussein Onn Malaysia, Pagoh Campus, 84600, Pagoh, Johor, Malaysia.

Received 15 September 2018; accepted 1 December 2018; available online 30 December 2018

DOI: https://10.30880/jst.2018.10.04.006

Abstract: An efficient system for nonlinear parameter characterization in Highly Nonlinear Fiber (HNLF) is described using four wave mixing (FWM) technique, the FWM plays an important role in enhancing the spectrum development in most cases. The Nonlinear parameters like zero-dispersion wavelength (ZDW), chromatic dispersion (CD) and the non-linear coefficient of HNLF were successfully investigated using this technique. The results of this technique have been almost identical to factory specifications. By FWM technique, a CD at 1550 nm slope is obtained from 0.007 ps.nm-2km-1, ZDW of 1531 nm and nonlinear parameters of 10.7 W-1km-1.

Keyword: Four wave mixing; highly nonlinear fiber; nonlinear coefficient; zero dispersion wavelength; chromatic dispersion.

1.0 Introduction

Nonlinear optical marvel in an optical fiber has turned into an essential character in the great of new frequencies, which finds numerous applications in the zone of parametric oscillation and multi-wavelength fiber lasers [1], wavelength converters [2] and optical switching [3]. This effect portrayed by the Kerr impact. There are a few techniques that have been previously detailed for estimating the fiber non-linear coefficient by using the technique of interferometric strategies [4] as self-phase modulation (SPM), cross phase modulation (XPM), modulation instability (MI), and four-wave mixing (FWM) [5]. At the point when optical signs are transmitted in an optical fiber, nonlinear marvels as FWM, SPM and XPM can happen. These kinds of nonlinear impacts can corrupt the nature of the optical signal, and breaking point the limit information, Therefore, it is requested to suppress the nonlinearities in optical fiber for broadcast communications [6]. A standout amongst the most imperative issues in enhancing the execution of these nonlinear optical fiber gadgets are expanding the nonlinearity of the fiber. Notwithstanding the way that the third-order nonlinear coefficient of silica glass is not intrinsically expansive, its nonlinearity can be expanded by such means as including a material with a high refractive index to the fiber center or decreasing the core measurement. To be sure profoundly nonlinear strands (HNLFs) have been studied for that have nonlinear coefficients around ten times more noteworthy than that of customary fiber [7].

A few methods have been proposed to characterize the nonlinear behavior of fibers, most of which are based on phase change detection or phase modulation. However, these techniques generally require short pulses and a small chromatic dispersion and only give the value of the CARE factor. A more applicable approach is the use of the four-wave mixing to measure the CARE coefficient and the dispersion at the same time. Since the fiber optic efficiency curve of FWM as a function of wavelength depends to a large extent on CD, ZDW and nonlinear fiber-optic processing, this technique becomes a common tool for measuring these parameters in fiber optics [8-15].

In this paper, we proposed a straightforward FWM technique to obtain an in-depth understanding of the nonlinear properties which influence the octave-spanning light generation by changing the signal wavelength and keeping the pump consistent.

*Corresponding author: norazura@uthm.edu.my

e-ISSN: 2600-7924/penerbit.uthm.edu.my/ojs/index.php/jst

2.0 Experimental setup

Fig. 1 shows a schematic diagram of the nonlinear parameter in the HNLF through FWM method. The fundamental segments are a 50 m long HNLF and a 3dB coupler. The HNLF is utilized like the nonlinear medium to create FWM while two signals (pump, PP, and signal, PS) travel in this fiber. In the setup, two VENTURI (TLB-8800) Tunable Laser Sources (assigned TLS1 and TLS2); with tuning ranges from 1515 nm to 1630 nm. Also, wavelengths of 0.015 nm are utilized as a signal, PS, and pump, PP sources. Both PP and PS are joined with a 3 dB coupler. Yokogawa (AQ6370D) Optical Spectrum Analyzer (OSA) with 0.02 nm determination data transfer capacity is utilized to analyze the FWM generation.

In the setup, we propose generating FWM for each S, C, L and U band. In the S-band region, the pump, PP at 1515 nm and the signal, PS is varying wavelength from 1515.2 nm to 1521 nm with an average power of 10 dBm are used which is shown in Fig. 2. For the C-Band region, PP at wavelength 1530 nm and PS is varied from 1530.2 nm to 1536.6 nm at 10 dBm are used which is shown in Fig. 3. Fig. 4 and Fig. 5 show graph spectrum for L band and U band region when PP at a wavelength of 1565 nm and 1625 nm are used for PS varying from 1565.2 nm to 1572 nm and 1625.2 nm to 1635 nm, respectively.

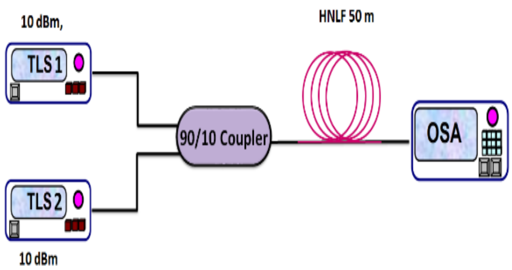

Fig. 1 Schematic diagram for generating FWM effect in the HNLF.

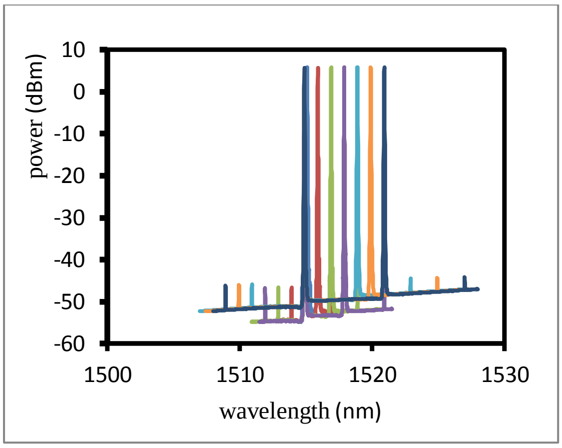

Fig. 2 Generating FWM in S-band.

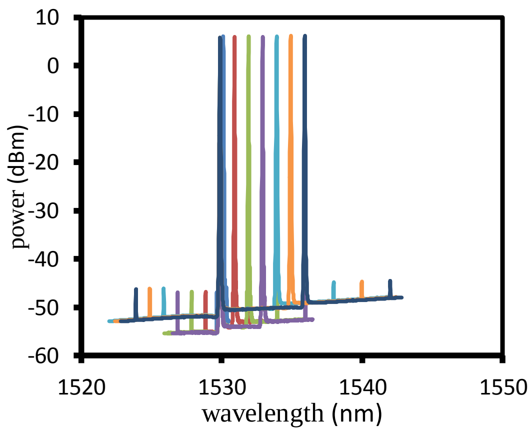

Fig. 3 Generating FWM in C-band.

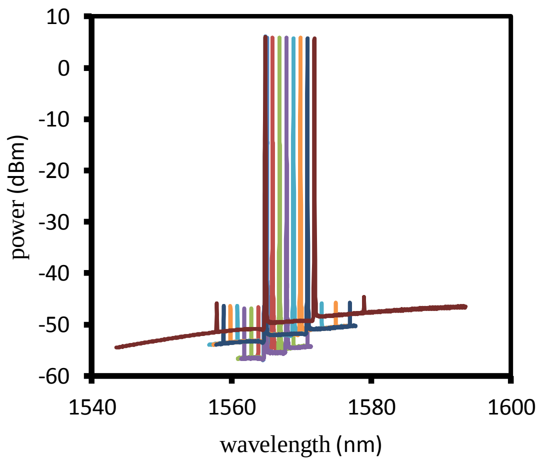

Fig. 4 Generating FWM in L-band.

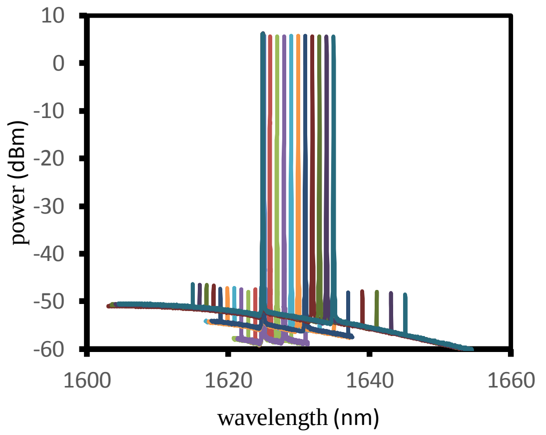

Fig. 5 Generating FWM in U-band.

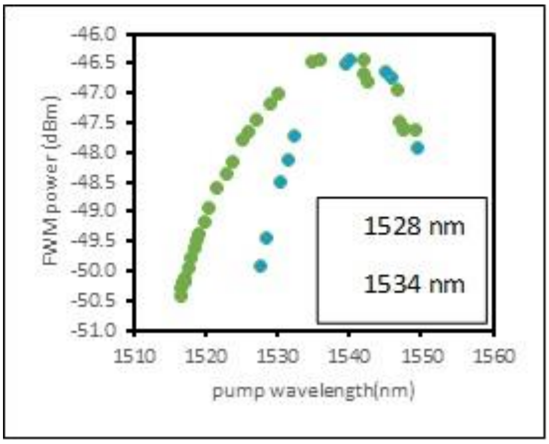

Fig. 6 The FWM efficiency against the wavelength and ZDW point.

3.0 Results and Discussion

In order to measure the ZDW, λo, FWM technique is used. By varying the pump and signal wavelengths, with a wavelength detuning of 0.3 nm in order to get the highest values of FWM power in the range 1510 nm to 1560 nm, shown in Fig. 3 to Fig. 5. In order to determine the ZDW, a TLS with broad tuning range is needed in this experiment. The scanning pump laser wavelength must pass over the ZDW of the HNLF to obtain a phase-matched FWM efficiency curve for a HNLF. Fig. 3 to Fig. 5 show that the generation of this idler depends on the power of the pump and signal wavelengths when a strong pump transfers its power to create the idler signal. From this spectrum, the FWM power is measured and the resulting spectrum is shown in Fig. 6 where it illustrates the clash point FWM power between both signal wavelengths at 1532 nm. This is because the phase-matching condition is fully satisfied at that point where it can be assumed as a ZDW. Therefore, the ZDW obtained from this technique is 1532 nm, which is approximately the ZDW value as provided by the manufacturer.

In order that verifies ZDW, we compare the measured value with our calculated result obtained from

$$P_F(L,\Delta\beta) = \eta(\Delta\beta)\gamma^2 L_{eff}^2 P_s P_p^2 e^{-\alpha L} \qquad (1)$$

where P_s and P_p are the two input source and pump powers at λ_(s)and λ_p source and pump wavelength, respectively, L is the length of the optical fiber and α is the absorption coefficient

$$\eta = \frac{\alpha^2}{\alpha^2+\Delta\beta^2}\left[1 + \frac{2e^{-\alpha L}(1-cos(\Delta\beta L))}{(1-e^{-\alpha L})^2}\right] \qquad (2)$$

and the phase-mismatching equation, Δβ as a function of the dispersion slope, S and pump wavelength

$$\eta = \frac{\alpha^2}{\alpha^2+\Delta\beta^2}\left[1 + \frac{2e^{-\alpha L}(1-cos(\Delta\beta L))}{(1-e^{-\alpha L})^2}\right] \qquad (3)$$

which demands the power and efficiency of FWM, η, respectively. These values can be obtained by adjusting the wavelength of the pump to a value lower than the ZDW value indicated by the manufacturer. Eq. 1 requires the HNLF fiber length, L, absorption coefficient, α, as well as the dispersion slope at 1550 nm == 0.007 ps/(nm2.km), which we obtained from the manufacturer's data sheet with values of L = 50 m, α = 0.000168 m-1, , respectively. Table 1 shows the comparison between nonlinear parameters of HNLF by the manufacturer and the experimental.

Table 1 Comparison between manufacture and experimental value.

Parameter	Unit	Manufacture	Experimental
Length	m	50	50
ZDW	nm	1531	1532
Dispersion slope at 1550 nm	ps/ ($nm^{-2}.km^{-1}$)	0.007	0.0065
Fiber attenuation	dB/km	0.73	0.73
Nonlinear coefficient	W^{-1} km^{-1}	10.8	10.7

REFERENCES

[1] Sun, H. B., Liu, X. M., Wang, L. R., Li, X. H., & Mao, D. (2010). Spacing-tunable multi-wavelength fiber laser based on cascaded four-wave mixing in highly nonlinear photonic-crystal fiber. *Laser Physics*, 20, 11, pp. 1994-2000.

[2] Zamzuri, A. K., Ismail, U. S., Al-Mansoori, M. H., Islam, M. S., & Mahdi, M. A. (2010). All-optical wavelength conversion based on degenerate four-wave mixing in Raman ring laser.Laser *Physics Letters*, 8, 1, pp. 62.

[3] Chu, P. L., & Wu, B. (1992). Optical switching in twin-core erbium-doped fibers. *Optics Letters*, 17, 4, pp. 255-257.

[4] Li, K., Xiong, Z., Peng, G. D., & Chu, P. L. (1997). Direct measurement of nonlinear refractive index with an all-fibre Sagnac interferometer. *Optics communications*, 136, 3-4, pp. 223-226.

[5] Chen, H. (2003). Simultaneous measurements of non-linear coefficient,zero-dispersion wavelength and chromatic dispersion in dispersion-shifted fibers by four-wave mixing. *Optics Communications*, 220, 4-6, pp. 331-335.

[6] Mitra, P. P., & Stark, J. B. (2001). Nonlinear limits to the information capacity of optical fibre communications. *Nature*, 411, 6841, pp. 1027.

[7] Okuno, T., Onishi, M., Kashiwada, T., Ishikawa, S., & Nishimura, M. (1999). Silica-based functional fibers with enhanced nonlinearity and their applications. *IEEE Journal of Selected Topics in Quantum Electronics*, 5, 5, pp. 1385-1391.

[8] Awang, N. A., & Ahmad, H. (2015). A simple nonlinear coefficient measurement of HNLF and ZrEDF by using four wave mixing technique.

[9] Vinegoni, C., Chen, H., Leblanc, M., Schinn, G. W., Wegmuller, M., & Gisin, N. (2003). Distributed measurements of chromatic dispersion and nonlinear coefficient in low-PMD dispersion-shifted fibers. *IEEE Photonics Technology Letters*, 15, 5, pp. 739-741.

[10] Marcuse, D., Chraplyvy, A. R., & Tkach, R. W. (1991). Effect of fiber nonlinearity on long-distance transmission. *Journal of Lightwave Technology*, 9, 1, pp. 121-128.

[11] Chen, H. (2003). Simultaneous measurements of non-linear coefficient, zero-dispersion wavelength and chromatic dispersion in dispersion-shifted fibers by four-wave mixing. *Optics Communications*, 220, 4-6, pp. 331-335.

[12] Liu, X. M. (2010). Broad and tunable multiwavelength fiber laser at the assistance of modulation-instability-assisted four-wave mixing. *Laser Physics*, 20, 4, pp. 842-846.

[13] Chen, D., Sun, B., & Wei, Y. (2010). Multi-wavelength laser source based on enhanced four-wave-mixing effect in a highly nonlinear fiber. *Laser Physics*, 20, 8, pp. 1733-1737.

[14] Grüner-Nielsen, L., Herstrøm, S., Dasgupta, S., Richardson, D., Jakobsen, D., Lundström, C., & Pálsdóttir, B. (2011). Silica-based highly nonlinear fibers with a high SBS threshold. *In Winter Topicals (WTM), 2011 IEEE*, pp. 171-172.

[15] Takahashi, M., Sugizaki, R., Hiroishi, J., Tadakuma, M., Taniguchi, Y., & Yagi, T. (2005). Low-loss and low-dispersion-slope highly nonlinear fibers. *Journal of Lightwave Technology*, 23, 11, pp. 3615-3624.