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Observation of Raman Gain in Reduced Length of Bismuth Erbium Doped Fiber

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Abstract: Raman amplification of a 49 cm Bismuth oxide (Bi_2O_3) as a nonlinear gain medium based erbium doped fiber amplifier (EDFA) is reported in new and compact design in near infrared spectral regions. The bismuth glass host provides the opportunity to be doped heavily with erbium ions to allow a compact optical gain fiber amplifier design by using reduced fiber length and the 1480 nm low pump power around 150 mW. A extended Raman amplification bandwidth of 45 nm, from 1520-1565 nm (C-band window) wavelengths is empirically proposed in a backward and dualwavelength pumped Bi-EDF by employing 350 mW Raman pump in 1440 nm. Because of the short length gain medium as a nonlinear Bi-EDF, amplification of 3 dB is achieved over a C-band wavelength range. This simple C-band Raman amplifier based Brillouin and ASE backscattering was constructed to test the forward, backward and dual-wavelength pump laser and on-off gain. A peak gain of 1.53 dB was obtained with a 3-dB bandwidth of 45 nm that the varieties of gain is 2.02 dB around 1545 nm in backward pumping design. It array will be employ for sensing, spectroscopy and telecommunication systems.

Keywords: Bi-EDF, Compact gain medium, C-band, Dual wavelength source, Raman gain.

1. INTRODUCTION

Optical fiber amplifiers are essential for increasing the scale and performance of communication systems[1]. Bi-doped glasses have many attractive features, which make it suitable as core fiber material of optical fiber. The near infrared spectral regions with wide luminescence in the range from 1000 ~ 1600 nm and the long lifetime of luminescence make such fiber promising for the

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development of compact lasers and amplifiers [2]. The erbium composition as a rare earth element represents the lowest distribution whereas the bismuth composition by refractive index up to 2.02, represent the highest distribution in comparison with other elements [3]. Bi₂O₃-based erbium doped fiber amplifiers (Bi-EDFAs) as a nonlinear gain medium are attractive devices for broadband flat signal amplification [4-8] even ASE source [9] with short gain medium lengths. The nonlinear effects in optical fiber due to inelastic scattering phenomenon, in which the optical field transfers part of its energy to the nonlinear medium. Such an inelastic-scattering phenomenon can induce stimulated effects such as Stimulated Brillouin Scattering (SBS), Stimulated Raman-Scattering (SRS) and Four Wave Mixing (FWM) phenomena that each type of stimulated scattering process that are due to the nonlinear properties of the Bi-EDF and it can be used as a special gain source [10]. The absorption spectrum of Bi-EDF exhibits a wider cross-section with two distinguishable peaks at 1495 and 1530 nm. Besides that, at the 1530 nm peak Bi-EDF has a higher absorption cross-section of 7.58×10^{-25} [m²] compared to 4.39×10^{-26} [m²] of Si-EDF, and larger full-width half maximum (FWHM) value which make that more suitable for broad band amplification with reduced length of fiber [3, 11]. Amplification that covers both the C and L-bands has been demonstrated in 22 cm and 26 cm long Bi-EDF using a tunable CW light source [4, 5]. A fiber based rare earth elements with a high erbium dopant concentration is expected to have enormous potential in realizing a compact erbium doped fiber amplifiers (EDFAs) and EDFA based devices [12]. Furthermore, fiber Raman amplifiers (FRAs) have special considerable attention as gain can be obtained over any wavelength region, provided a suitable pump source is used. Hence, multiple pump sources at different wavelengths and low pump power can be used to shape and extend the Raman gain spectrum [13]. In other report, the gain media of the Raman/Bi-EDFA is only a 2.15 m Bi-EDF pumped bi-directionally by two laser diodes (LDs) [11].

In this letter, an efficient CW-pumped fiber optical amplifier (FOA) in a reduced length around 49 cm Bi-EDF has been studied in three processes. On: off gain greater than 1.5 dB are achieved in 1550 nm wavelength range in C-band (1520-1565 nm) based nonlinear gain medium of Bi-EDF. Dual-wavelength operation used to provide higher peak output and four wave-mixing applications in convert wavelength.

2. EXPERIMENTAL SET-UP

Figure 1 shows the experimental setup for investigating the Raman amplification properties of a 49 cm Bi-EDF, that it performed in photonic research center of University of Malaya (UM). The erbium concentration of the

Bi-EDF was 3250 wt.ppm, the mode-field diameter and the numerical aperture at 1550 nm were 6.12 μm and 0.20, respectively. The reduced length of Bi-EDF used in this experiment is commercially available from Asahi Glass Co. and it contains an Er^{3+} ion concentration of 7.6×10^{25} ions/ m^3 with a Lanthanum ion codopant concentration of approximately 4.4 wt% which it has absorption coefficient $58.3(\text{w.km})^{-1}$ in 1550 nm region. Furthermore, this fiber has a core/cladding refractive index of 2.03/2.02. Both ends of Bi-EDF were specially fusion spliced to SiO_2 fibers as angle in order to reduce splice point reflections with a loss per splicing of less than 0.7 dB [5]. The optimum pump wavelength for Raman gain amplification in the Bi-EDF was in interval wavelength 1540-1550 nm for three types using forward, backward (double pass) and dual wavelength. The backward signal from first tunable laser source (TLS1) and the forward signals of two TLS2 and TLS3 are also compared for amplifying of special selective signals results. The backward signal was multiplexed in an optical circulator (OC), and two other signals launched into the gain fiber via the isolators and wave division multiplexing (WDM) couplers in forward direction. The Raman pump operating at 1440 nm, which was coupled into the gain fiber via a 3dB coupler. The maximum Raman pump power launched into the gain fiber was 350 mW. One wave selective coupler (WSC) inject the 1480 nm pump laser source around 150 mW into Bi-EDF. As we shown in figure 1, the output is characterized using an optical spectrum analyzer (OSA).

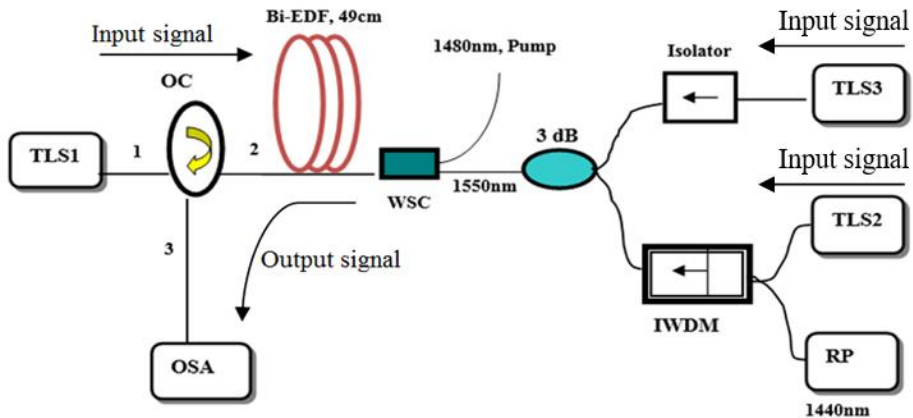


Fig. 1. Schematic diagram for optical fiber gain measurement in three processes; forward, backward and dual-wavelength pump laser.

3. RESULT AND DISCUSSION

First of all, we have been investigated amplification in only 49 cm Bi-EDF without Raman pump by employing 1480 nm pump in maximum power 150 mW. The gain (G) and noise figure (NF) are measured by an optical spectrum analyzer (OSA), automatically. Fig. 2 compares the gain and noise figure of the Bi-EDFA in forward and backward (double pass) at input signal of 0 dBm. By employing TLS1 in backward, the gain of the Bi-EDFA is in interval 5.4-6.3 dB higher than forward gain that TLS3 produced it. The flat gain profile bandwidth Bi-EDF in both method is approximately 40 nm spanning from 1530 nm up to 1570 nm, which in forward is completely flat. The important view in this configuration is achieving to noise figure as such as 5 dB less in double pass method. The origin of noise in this array is due to nonlinear gain medium that made amplified spontaneous emission (ASE) noise type which in back ward signals, we can see the effect in figure 2 that is noise is minimum manner because it have deactivated by amplifying of Brillouin scattering in nonlinear Bi-EDF as a gain medium. The Brillouin scattering is always is in backward direction of signals.

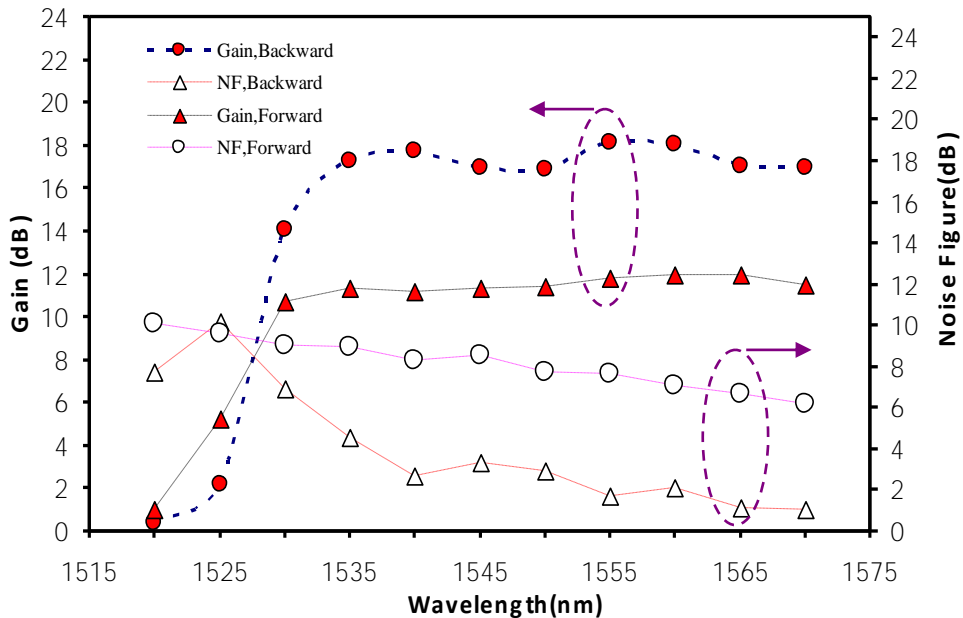


Fig. 2. Comparison of the measured signal gain and noise figure at input signal power of 0 dBm between forward and backward (double pass) methods.

Fig. 3 shows the gain on-off of the test C-band FRA for forward, backward and two dual-wavelength tunable laser source configurations. Raman pump on-off gain can be approximately described by $G_A = \exp(g_R P_0 L_{\text{eff}} / A_{\text{eff}})$, where g_R is equal by Raman gain coefficient, P_0 (pump power), L_{eff} (effective length) and A_{eff} (effective area)[14 , 15]. Gain flattening was achieved by optimizing the powers in the lasing lines of forward and the dual-wavelength by fluctuation less than 0.8 dB. The fluctuation less than 1 dB is ideal condition for nonlinear gain medium due to reduced length of Bi-EDF.

When the usage of backward method (TLS1), a peak gain of 1.53 dB was obtained with a 3-dB bandwidth of 45 nm. In this case, the varieties of gain is 2.02 dB around the 1545 nm peak power. Backward amplification has many applications special in Brillouin amplifiers and special fiber lasers[16]. Probably, by employing higher Raman pump powers (>350 mW) near to watt and components with less loss can obtain higher gain in future work.

Dual-wavelength lasing occur from two forward tunable laser sources (TLS2, TLS3). However, when both pumps were used at the same power and wavelength, gain on/off more than 0.4 dB cover the 1530- 1555 nm regions special around Raman gain (1530 nm and 1540 nm). Despite of low gain in this method, we obtain higher peak power (Fig.4) and more stability for convert wavelength applications based FWM phenomena as an other nonlinear effect in the fiber gain medium. As a result more flattening gain observed in forward case in 1530-1540 nm area Raman gain but it has little gain around 0.23 nm only.

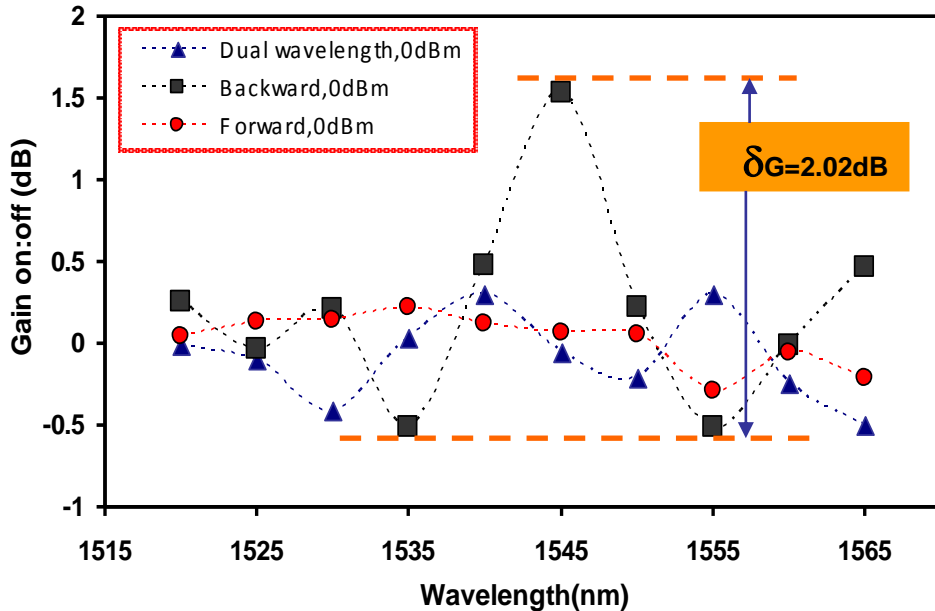


Fig. 3. The comparison of On–off Raman gain spectra of the Bi-EDFA for pump powers of 350 mW in three conditions.

Figure 4 shows the peak power spectra as a function of signal pump powers (BP). The Raman pump fixed in 350 mW and 1480 pump power is around 150 mw. In two cases of forward and dual wavelengths, increased signal powers resulted in gain peaks but we obtained maximum peak power in 4-5 dBm in backward according to optimum power for Brillouin backscattering [10, 17, 18]. Then, the lower peak powers and some fluctuation of peaks in this part is due to Brillouin backscattering and also amplified spontaneous emission [ASE] as a type of noise [19] in nonlinear gain medium like Bi-EDF that by thermal controlling and air cooling on the environment of source achieved stability during the long time. The noise figure is also dependent on both the pumping power and the segment length where the gain is realized [15].

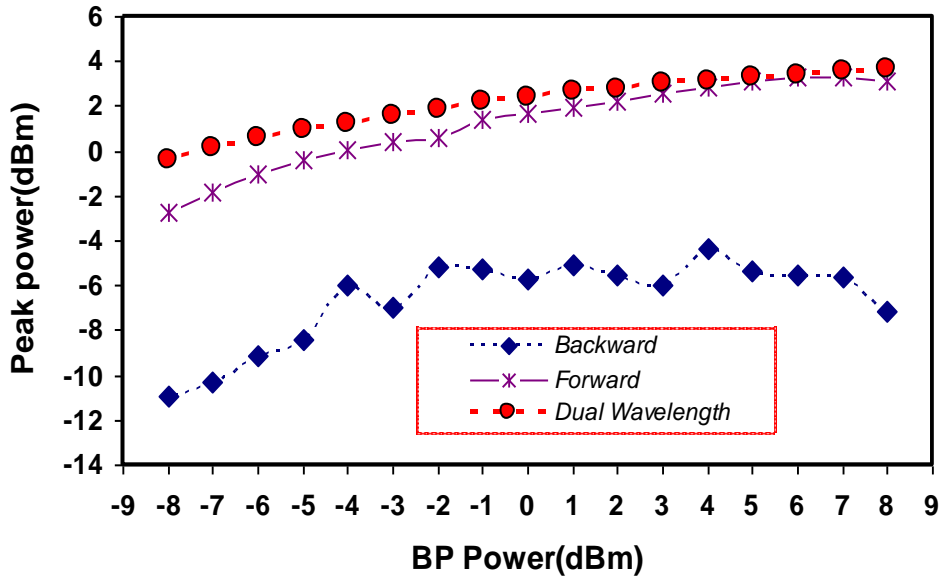


Fig. 4. Peak powers in 1550 nm as a function of Brillouin pump power.

Figure 5 shows that gain on/off as a function of 1480 nm pump powers in backward process. We can observe gain lower than 0.1 dB below 68 mW pump power. It demonstrated that nonlinear Bi-EDF because of high absorption coefficient and refractive index in this region in compare to normal Si-EDF need to suitable pump under controlling temperature for amplifying and Raman pumping[20]

. The nonlinear Bi-EDF gain medium is extremely depending to temperature condition that we tuned systems below 25°C for long time stability around 3-4 hour. However, the stability of results is controllable by keeping the physical conditions like temperature, air cooling laser source [21, 22] and time interval. In this figure, we also proposed output and input power for clarify obtained gain in backward pumping. The output gain power is achieved around -5 dBm.

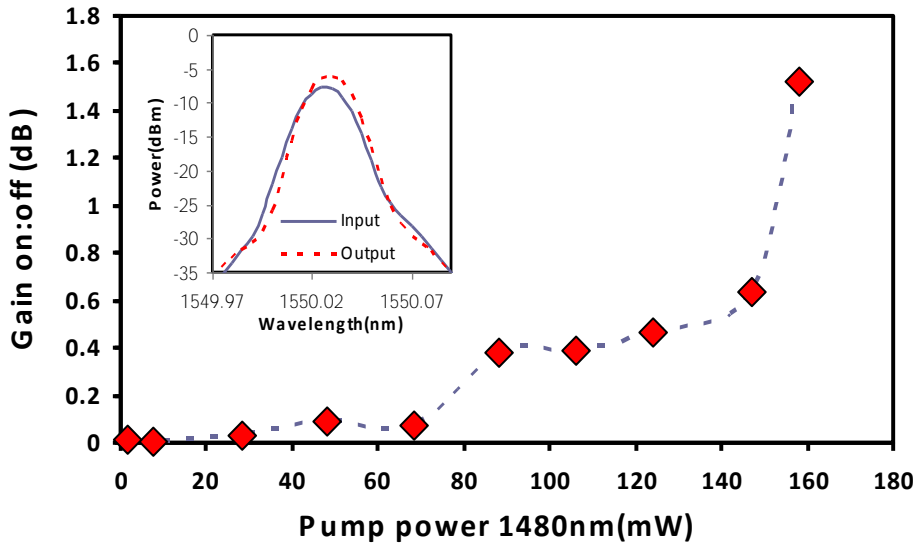


Fig. 5. On:off optical gain as a function of pump power 1480nm. Maximum gain of 1.53 dB is obtained in backward design in 160 mW.

4. CONCLUSION

In conclusion, a novel Raman-assisted reduced length Bi-EDFA has been demonstrated. The optimum optical on-off gain 1.53 dB using Raman amplification in only 49 cm Bi-EDF gain media achieved at peak pump powers of 350 mW in the backward method. Raman gain has a high speed response that in principle, in fiber the entire bit stream can be amplified without any distortion in high bit rate systems. Dual wavelength sources control gain flattening in a test Bi-EDFA over C-band for four wave mixing applications in convert wavelengths. This type of array by reduced nonlinear gain medium (Bi-EDF) by high refractive index need to control low temperature for stability output and the fluctuations of spontaneous emission noise. However, this compact broadband seed source could be used with an appropriate commercial stabilized source, such as a diode laser and complicated amplifiers that is suitable as a laboratory amplifier, although improvements would be necessary for sensing, spectroscopy and telecommunication systems.

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