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# A WIDEBAND AND FLAT-GAIN OF AN AMPLIFIER BY USING ZIRCONIA-BASED ERBIUM-DOPED FIBER (ZR-EDF) FOR SINGLE PASS PPERATION

Arni Munira Markom[a,b]*, Harith Ahmad[c] and Sulaiman Wadi Harun[a]*

[a]Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b]Department of Electronic Engineering, Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
[c]Photonics Research Centre, Department of Physics, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia

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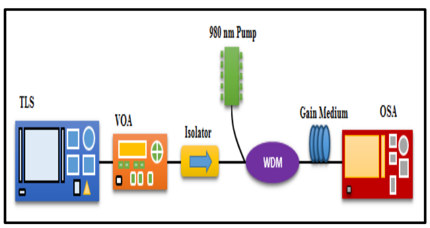
*Corresponding author
arnimunira@gmail.com

**Graphical abstract**




**Abstract**

An amplification for single pass operation was demonstrated by using Zirconia-based erbium-doped fiber (Zr-EDF). 1 m is the optimum length due to overall high gain and minimal noise figure from 1520 nm to 1620 nm. The highest gain is 28.62 dB at 1555 nm with the input signal and pump power are fixed at -30 dBm and 130 mW, respectively. At input signal -10 dBm, a wide and flat-gain of 19.36 dB is obtained with very small variation gain of 0.27 dB from 1530 nm to 1570 nm. Meanwhile, the noise figure for both input signals were maintained below than 12 dBm for the specific regions.

*Keywords*: Zirconia fiber, wideband, flat-gain, erbium-doped fiber, amplifiers

**Abstrak**

Penguat untuk operasi perlepasan tunggal telah dilaporkan menggunakan gentian didopkan Zirconia erbium (Zr-EDF). 1 m merupakan panjang optima fiber kerana keseluruhan pengganda yang tinggi dan angka hingar yang rendah dari 1520 nm sehingga 1620 nm. Pengganda tertinggi adalah 28.62 dB di 1555 nm dengan isyarat kemasukan dan kuasa pam ditetapkan pada -30 dBm dan 130 mW. Pada isyarat kemasuka -10 dBm, pengganda yang lebar dan rata 19.36 dB diperolehi dengan variasi pengganda yang sangat kecil iaitu 0.27 dB dari 1530 nm sehingga 1570 nm. Manakala angka hingar untuk kedua isyarat kemasukan stabil di bawah 12 dBm untuk kawasan yang ditetapkan.

*Kata kunci:* Gentian zirconia, jalur lebar, pengganda rata, gentian erbium-dop dan penguat.



## 1.0 INTRODUCTION

Nowadays in telecommunication systems, the fastest transportation for carrying information is by using light which is guided in optical fibers. The combination with fiber amplifier boost a significant development in advance optical communications and welcomed to the era of fiber-to-the-home deployment [1]. Fundamentally, amplification was achieved when the pump of laser excited the electrons in the atoms, causing them to move from lower to higher energy levels and this phenomenon known as population inversion. Then, the important keys for optimum results from an amplifier are high optical gain, wideband, flatness gain and minimum noise figure [2]. To date, the most practical amplifier was erbium-doped fiber amplifiers (EDFA) due to the reliability properties such as high gain with low pump power, low noise figure, and wideband amplification spectrum from S-band to the L-band regions [3-7].

In our previous work, a wideband Erbium-doped fiber amplifier (EDFA) is demonstrated using a new type of Erbium-doped fiber (EDF), which is fabricated in a ternary glass host, zirconia-yttria-aluminum (Zr-Y-Al) co-doped silica fiber. With a combination of both Zr and Al, we could achieve a high erbium doping concentration of 2800 ppm in the glass host without any phase separations of rare-earths [8-10]. It is found that a zirconia co-doped EDFA (Zr-EDFA) can achieve a better flat-gain, broadened wavelengths and lower noise figure compare to conventional Bismuth-based EDFA [11-13]. In this paper, an improved Zr-EDF as gain medium with high doping for glass host material of $ZrO_2$ and $Al_2O_3$, resulting in high erbium concentration ions and high refractive index in core fiber is proposed. Thus, an efficient Zr-EDFA with an improved gain and noise figure is demonstrated in conjunction with a single pass configuration.

## 2.0 FABRICATION

A new class of Zr-Y-Al co-doped EDF with a higher Erbium ion concentration is developed in this study. At first, a Zr-Y-Al co-doped EDF preforms based on zirconia-yttria–alumina-phospho silica glass with a high doping level of $ZrO_2$ around 2 wt% is fabricated using the modified chemical vapour deposition (MCVD) process. The doping of $Er_2O_3$ into the zirconia-yttria-alumina-phospho silica based glass is done via solution doping process [14]. A small amount of $Y_2O_3$ and $P_2O_5$ is added at this stage to serve as a nucleating agent. This step is necessary to increase the phase separation for the generation of $Er_2O_3$ doped micro crystallites in the core matrix of optical fiber preform [8-10]. The glass formers incorporated by the MCVD process are $SiO_2$ and $P_2O_5$ along with the glass modifiers $Al_2O_3$ ,$ZrO_2$, $Er_2O_3$ and $Y_2O_3$, which are also incorporated by the solution doping technique using an alcoholic-water mixture of suitable strength (1:5) to form the complex molecules $ErCl_3.6H_2O$, $AlCl_3.6H_2O$, $YCl_3.6H_2O$ and $ZrOCl_2$ $8H_2O$. The inclusion of the $Y_2O_3$ particulates into the host matrix also serves the additional purpose of slowing down or eliminating changes in the $ZrO_2$ crystal structure. This is a crucial factor in the fabrication process. Pure zirconium dioxide can exist in three distinct crystalline structures in a bulk glass matrix, depending on the temperature range. Figure 1 shows the dopant distribution profiles of the fiber for the dopants used.

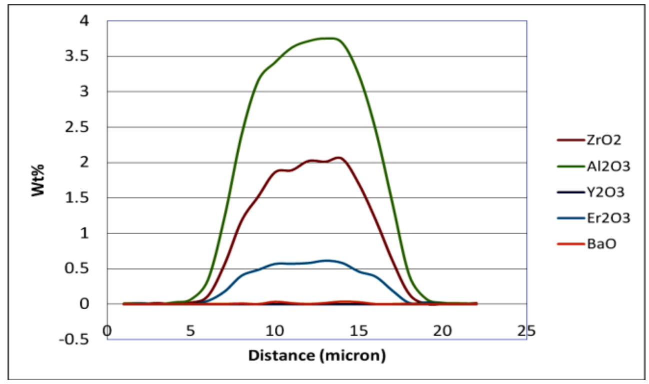



**Figure 1** Dopant distribution profile of the fiber

The fiber was drawn at around 2000 $^0$C from the annealed preform and simultaneously coated with resin using fiber drawing tower. The nano-crystalline host of $ZrO_2$ was preserved in the silica glass matrix as confirmed by the transmission electron microscopy (TEM) analyses with energy dispersive X-ray analysis (EDX) spectra and electron diffraction patterns [8]. The average particle sizes were around 10–20 nm. The core and cladding geometry of the fiber was inspected by an optical microscope (Olympus BX51). The core was homogeneous and had no observable defects at the interface between the core and the silica cladding. The core and cladding diameters of the fiber at 10.04 μm and 126.83 μm, respectively. Figure 2 shows the dopant distribution profile of Zr-EDF which contains $SiO_2$, $Al_2O_3$, $Y_2O_3$, $ZrO_2$, $P_2O_5$ and $Er_2O_3$ doping host in the core and a numerical aperture of 0.17. The spectral attenuation curve of the fiber is given in Figure 2 and it shows 80.0 dB/m absorption loss at 980 nm wavelength.

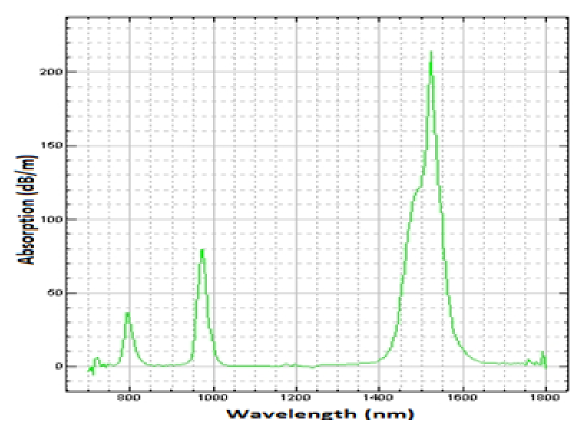



**Figure 2** The absorption loss curve of the enhanced Zr-EDF with high $ZrO_2$ co-doping

## 3.0 EXPERIMENTAL

Figure 3 illustrated the experimental setup of the single-pass optical amplifier by using zirconia-based erbium-doped fiber (Zr-EDF) as the gain medium. Then, tunable laser source (TLS) as input of photons was varied from 1520 nm to 1620 nm wavelengths of region in conjunction with variable optical amplifier (VOA). The VOA used to obtain the specific and accurate input power to the cavity. An isolator is placed after input power to prevent a backward ASE noise from entering the first stage and parasitic lasing which cause degrading the optical gain of amplifiers. The gain medium, also known as active material was pumped by 980 nm laser diode which is combined with 980/1550 nm wavelength division multiplexing (WDM) coupler. The results were analyzed and measured by optical spectrum analyzer (OSA) at the end of the configuration setup of single pass amplifier.

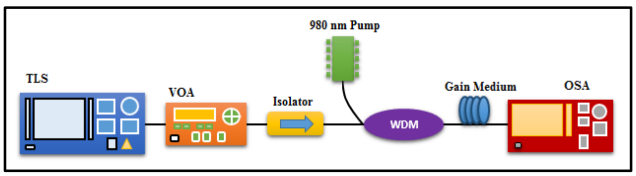



**Figure 3** Configuration of the single-pass optical amplifier

## 4.0 RESULTS AND DISCUSSION

The amplifier performance is investigated by using Zr-EDF named as ER-3 fiber at three different lengths and the results shown in Figure 4. The lengths of fiber are varied from 0.5 m to 2 m while the pump power and the input signal are fixed at 130 mW and -30 dBm, respectively. Then, the length of 1 m showed as the highest performance for overall optical gain with average 18.11 dB from 1520 nm to 1620 nm wavelengths region. Moreover, three highest optical gain is obtained at 1535 nm, 1550 nm and 1555 nm wavelengths with the value are 28.46 dB, 28.19 dB and 28.62 dB. However, all the fibers are observed gave a similar trend when the gain is slightly dropped at L-band region due to saturation effect. Meanwhile for noise figure, all fiber maintained below 12 dB due to amplified spontaneous emission (ASE) noise increased within the amplifier. ASE noise originates from mixing the coherent signal with the incoherent ASE noise in the same polarization when the gain medium is pumped to produce population inversion in cavity.

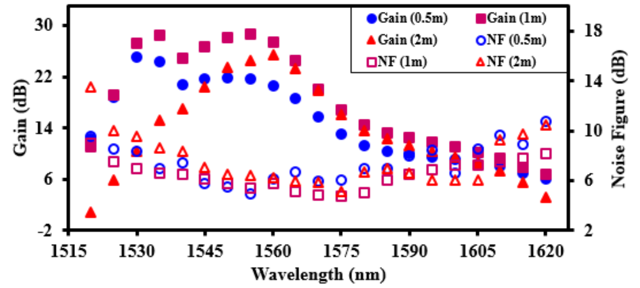



**Figure 4** Optical gain and noise figure spectrum at -30 dBm input signal and 130 mW pump power for different lengths of ER-3 fiber

Meanwhile for input signal at -10 dBm, with the same pump power and lengths of fibers are investigated and the results shown in Figure 5. Again, the 1 m length obtained the overall highest gain with the highest value is 19.86 dB at 1555 nm wavelength. A wide flattening gain is obtained with very small variation gain of 0.27 dB within 1530 nm to 1570 nm wavelengths. Moreover, 1 m length achieved higher average flat-gain of 19.36 dB compare to other length of fibers. The 0.5 m length of fiber also successfully obtained a flat-gain of 13.3 dB with a small variation gain of 0.23 dB from 1530 nm to 1565 nm wavelengths. However, the flat-gain is less and narrow region compare to 1 m length. Thus, 1 m length is optimum length for improved Zr-EDF. Then, the noise figure maintained below than 12 dBm for the specific regions.

The experiment is continued with three different pump powers of 61 mW, 87 mW and 130 mW while the input signals were fixed at -30 dBm. The results shown in Figure 6. The experiments use the optimum length of 1 m. As a results, the optical gain was gradually increased with the increment pump power due to the increase spontaneous-stimulated emission through the fiber.

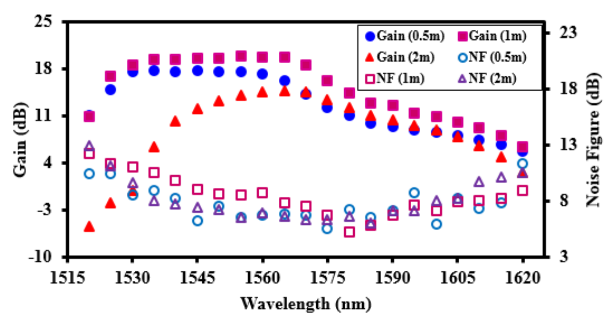



**Figure 5** Optical gain and noise figure spectrum at -10 dBm input signal and 130 mW pump power for different lengths of ER-3 fiber

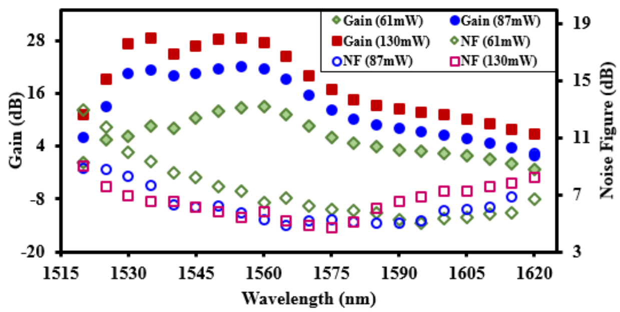



**Figure 6** Optical gain and noise figure of 1 m length for ER-3 fiber at different pump power where the input signal fixed at -30 dBm

At input signal -30 dBm, the gain is increased as high as 42.43 % when the power changed from 61 mW to 87 mW. Then, when the power was increased to the maximum of 130 mW, the overall gain is improved as high as 16.89 %. For instance at wavelength 1555 nm, the gain increased from 12.74 dB to 22.03 dB as the power was changed from 67 mW to 87 mW. Then, the gain is continued increases to 28.62 dB with the increment maximum power of 130 mW. Meanwhile for noise figure, the results are decreased as increasing the pump power. Therefore, 130 mW with the highest gain gives the lowest noise figure because this noise inversely with optical gain and linearly to the ASE power due to efficient population inversion.

Next is a comparison between previous Zr-EDF (NER-6) with the current fiber of ER-3, where the input signals and pump power are fixed at -30 dBm and 130 mW, respectively. The results are described in Figure 7. Again, 1 m length is used due to optimum length of ER-3 fiber. Then, ER-3 fiber showed an improvement 7.69 % for gain performances compare to NER-6 fiber. The average optical gain for ER-3 was 18.11 dB while 15.52 dB for NER-6 due to high erbium ions concentration doping in ER-3 fiber. It increased the population inversion in the cavity cause the improvement of gain and noise figure. Both fibers were successfully achieved a flat-gain because zirconia-based is a good host material with high refractive indices of 2. Thus, it produces a uniform gain with a broadened wavelength region. However, ER-3 results had overcome the older fiber with increment of 27 % due to a very small variation gain of 0.27 dB compare to 0.47 dB for NER-6 fiber. Meanwhile the noise figure results were slightly similar for both fibers and maintained below 12 dB from 1520 nm to 1620 nm wavelengths.

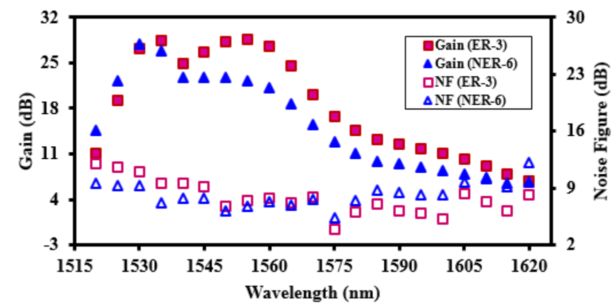



**Figure 7** Optical gain and noise figure of the 1 m length for ER-3 (new) and NER-6 (old) fiber

## 5.0 CONCLUSION

To conclude, amplification of optical gain and noise figure characteristics were experimentally demonstrated by using Zirconia-based erbium-doped fiber (Zr-EDF) with various types of lengths, pump powers and input signal powers. At input signal -30 dBm, three highest optical gain are obtained at 1535 nm, 1550 nm and 1555 nm wavelengths with the gain value of 28.46 dB, 28.19 dB and 28.62 dB. Meanwhile at input signal -10 dBm, a wideband and flatness gain of 19.36 dB was obtained with a very small variation gain of 0.27 dB within 1530 nm to 1570 nm. The noise figures showed a slightly high results but maintain below 12 dB from 1520 nm to 1620 nm region for the specific regions.

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