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*Research paper*

# Performance Comparison of Zirconia, Bismuth and Silica-doped Erbium Fiber for Optical Amplification

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**Abstract**

Zirconia-based Erbium-doped fiber amplifier (Zr-EDFA) is improved material optical fiber with more than 4000 ppm erbium-doped concentration to solve global demand for huge capacity carrying data information, high speed transmission and long haul with specific devices of compactness. Thus, the length of Zr-EDFA is only 50 cm as gain medium. At input pump power -30 dBm, the highest optical gain is 34 dB (1530 nm wavelength) whereas 21 dB (1535 nm wavelength) at -10 dBm. Besides, the flatness gain 21 dB with fluctuation of 1 dB is recorded for Zr-EDFA. For performance comparison, Bismuth-based Erbium-doped fiber amplifier (Bi-EDFA) and Silica-based Erbium-doped fiber amplifier (Si-EDFA) were also investigated.

***Keywords***: *EDFA; Zirconia; Bismuth; Silica-doped and Optical amplifier*

## 1. Introduction

Optical amplifier is a device used to amplify optical signals directly without converting to electrical signals. Erbium doped fiber amplifier (EDFA) is dominant amplifier for past decades as it are less difficult to fabricate, able to carry a massive signal capacity, and relatively low cost. Besides, EDFA is widely used in remote sensing, laser range finding, communications, marking, micro-machining, biomedical imaging and medical surgery [1-2]. The use of EDFA in these areas is increasing, globally. In addition to the use of Erbium, other rare earth elements are experimenting to increase the optical amplifier performance and efficiency such as Praseodymium ($Pr^{3+}$), Ytterbium ($Yb^{3+}$), Terbium ($Te^{3+}$), and Thulium ($Tm^{3+}$) and Zirconium (Zr) [1-2]. The rare earth elements have advantages such as easy energy levels, have higher life expectancy at high levels, have quantum efficiency and have a spectral absorption rate that enables more development in high-power fiber lasers [3]. However, due to the growing demand due to the growing growth rate in traffic telecommunication sparking more advanced transmission system where it has more capacity, greater bandwidth and high data speeds. Therefore, Zirconium is seen to be another excellent candidate in the field of optical fiber because of having a refractive index that exceeds 1.45 in the visible and near infrared spectrum, thus having wider emission and absorption rates from C- to the extended L- bands [4-5]. More studies on improving gain and reducing noise figure have been done on the use of Zirconium in optical amplifiers and these studies have shown that Zirconium has a better potential.

## 2. Methodology

The scope of work can be divided to four main tasks as stated below:

**(a) Design and modelling**
Zirconia co-doped Erbium-doped fiber (Zr-EDF), Bismuth co-doped Erbium-doped fiber (Bi-EDF) and Silicon co-doped Erbium-doped fiber (Si-EDF).Zr-EDF, Bi-EDF and Si-EDF are theoretically designed for long applications in an efficient 1510 nm – 1620 nm transmission region.

**(b) Fabrications of Zr-EDF**
Zr-EDF, Bi-EDF and Si-EDF are fabricated using a modified chemical vapour deposition process in conjunction with solution doping process.

**(c) Characterization and optimization of the fiber parameters**
Characterization and optimisation of the fibre's property are very important to an efficient Zr-EDF, Bi-EDF and Si-EDF lasers. The elements of characterize is preform and fibre diameters, lifetimes, emission and absorption characteristic, attenuations, refractive index etc. New sciences may be discover during this research stage.

**(d) Experiment on Zr-EDF, Bi-EDF and Si-EDF for amplifier and fiber lasers**
The amplifier and fibre lasers are demonstrated using the fabricated Zr-EDF, Bi-EDF and Si-EDF as a gain medium.
Figure 1 illustrates the configuration of experimental setup for double-pass optical amplifier by using Zr-EDF and Bi-EDF as gain medium. The absorption, spontaneous emission, and stimulated emission have been identified as three process of light emission as shown in Figure 1.

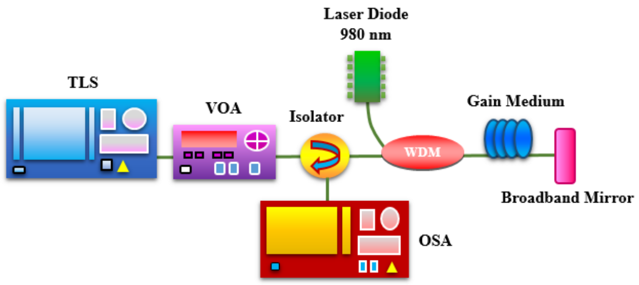


**Fig.1:** Configuration of experimental setup for double-pass optical amplifier by using Zr-EDF and Bi-EDF as gain medium

The gain medium is forward pumped by a 980 nm laser diode which provides optical energy in fiber to stimulate the electrons to excited bands. Tunable laser diode (TLS) in conjunction with variable optical amplifier (VOA) are used to give the specific input signal for each wavelengths of operation. At the optimum pump power, amplifier performance is investigated for two input signal of -30 dBm (low input) and -10 dBm (high input). The range of wavelengths is varied from 1515 to 1620 nm and together with optical spectrum analyzer (OSA) for gain and noise figure measurement of the amplifiers. An isolator is placed via a 980/1550 nm wavelength division multiplexing (WDM) coupler to prevent any backward amplified spontaneous emission (ASE) noise to the cavity.

## 3. Result and Discussion

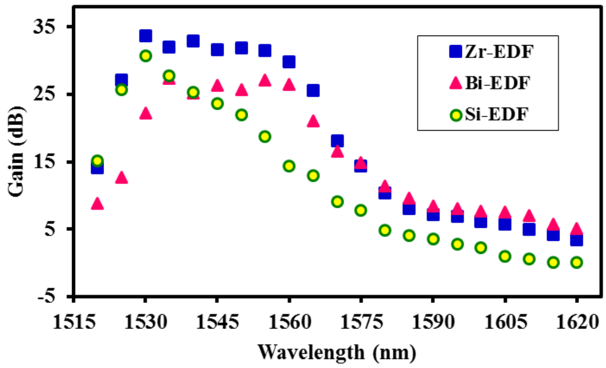


**Fig.2:** Gain analysis of -30 dBm Zr-EDF, Bi-EDF and Si-EDF

As short as 50 cm of gain medium is utilized to the configuration arrangement aimed for compact device applications. Two imperative components of optical gain and noise figure (NF) with two different input pump powers of -30 dBm and -10 dBm are examined, respectively. Moreover, three different gain mediums of zirconia-based erbium-doped fiber (Zr-EDF), bismuth-based erbium-doped fiber (Bi-EDF) and silica-based erbium-doped fiber (Si-EDF) are being used to make performance comparison. Figure 2 shows -30 dBm gain analysis of Zr-EDF, Bi-EDF and Si-EDF versus wavelength from 1520 nm to 1620 nm. As expected, Zr-EDF shows the highest gain between 1530 nm – 1560 nm wavelength, but then it started to decrease from 1565 nm until 1620 nm wavelength. The uppermost optical gain are 34 dB (1530 nm), 27 dB (1555 nm) and 31 dB (1530 nm) for Zr-EDF, Bi-EDF and Si-EDF.

Figure 2 and 3 of Zr-EDF and C-band also show the uppermost gain for both input powers can be achieved because the ability can be doped with erbium concentration up to 4000 ppm when compared to other fibers. With doped concentration in abundance, it will stimulate emission progression where a massive of excited electrons transform to coherent photons of optical gain for amplification. Even though Bi-EDF has more erbium concentration, the big different numerical aperture (NA) about 2.0 cause a big losses of optical gain when integrate with 0.17 commercial fiber. Meanwhile, Si-EDF shows the lowest optical gain for the most wavelengths due to lowest erbium concentration doping. It determines that Si-EDF is not suitable for compact devices.

This is due to the up-conversion process that suppresses the amplification at an extended L-band region. This effect is less in the Bi-EDFA owing to incorporation of lanthanum ions. The large core diameter of Zr-EDF contributes to the improvement due to more useful light was traveling through the core, lowering the loss inside the fiber and thus it enhances the population inversion in the active fiber. There the Zr-EDF is expected to be preferable than Bi-EDF to provide high flatness gain in wideband transmission distance with very short length of gain medium, and realizes the future miniature and compact device systems.

The red-shift in the operating wavelength of the EDFA with a longer EDF is attributed to a quasi-two level system effect in the gain medium which absorbs the shorter wavelength photons and emits at longer wavelengths.

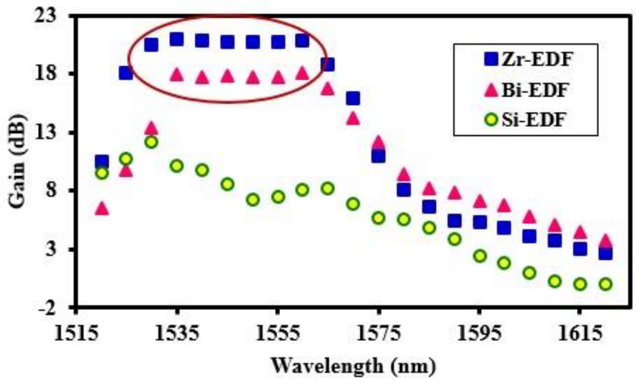


**Fig.3:** Gain analysis of -10dBm Zr-EDF, Bi-EDF and Si-EDF

Figure 3 shows -10 dBm gain analysis of Zr-EDF, Bi-EDF and Si-EDF versus wavelength. Once more, Zr-EDF shows the uppermost gain between 1520 nm – 1555 nm wavelength and decreases from 1560 nm – 1620 nm. Bi-EDF shows increment from 1520 nm until 1535 nm. Then then gain is flattened between 1535 nm and 1560 nm wavelength. After 1560 nm, the gain decreases until 1620 nm wavelength. Meanwhile, Si-EDF shows the lowest gain in most wavelength. Compared to -30 dBm input pump power, -10 dBm is successfully in obtaining flatness gain. Flat-gain is also defined as uniformity gain for all wavelengths and critical for long haul applications with many amplifier platforms. This is because all noises for every amplifier platforms will be accumulated and become larger until to the end of transmission link which degrades the overall performance of communication systems. Then, Zr-EDF and Bi-EDF are obtained average flatness gain of 21 dB and 17 dB with very small fluctuation of 0.03 dB and 0.2 dB, correspondingly.

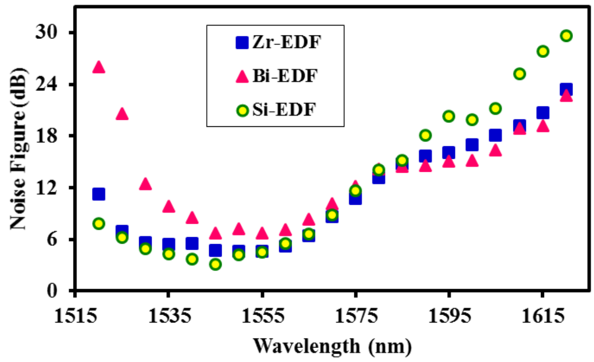


**Fig.4:** Noise figure analysis of -30dBm Zr-EDF, Bi-EDF and Si-EDF

Figure 4 shows -30 dBm noise figure analysis of Zr-EDF, Bi-EDF and Si-EDF versus wavelength. Between 1515 nm-1575 nm wavelength, Bi-EDF shows the highest noise figure, while Si-EDF shows the lowest noise figure.

Meanwhile, between 1575 nm-16155 nm wavelength, Si-EDF shows the highest noise figure, while Bi-EDF shows the lowest noise figure. Result shows are based on the characteristic of Bi-EDF which has refractive index difference at 0.010 and numerical aperture (NA) is 0.20. Besides, its core diameter is 4.5 micrometer which is smaller compared to Zr-EDF which is 10.04 micrometer

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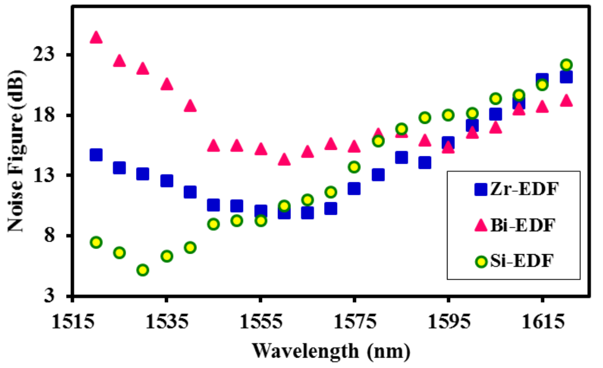


**Fig.5:** Noise figure analysis of -10dBm Zr-EDF, Bi-EDF and Si-EDF

Figure 5 shows -10dBm noise figure analysis of Zr-EDF, Bi-EDF and Si-EDF versus wavelength. Between 1515 nm-1555 nm wavelength, Bi-EDF shows the highest noise figure, while Si-EDF shows the lowest noise figure.

Meanwhile, between 1555 nm-1575 nm wavelength, Bi-EDF shows the highest noise figure, while Zi-EDF shows the lowest noise figure. However, after 1575 nm wavelength, the noise figure of Zr-EDF, Bi-EDF and Si-EDF fluctuate and intercept each other.

The decrement and increasing of noise figure of Si-EDF is due to strong growth of is due to strong growth of ASE noise at longer wavelength region in double-pass system which the signal is amplified twice. The formation of flat-gain spectrum for the Si-EDFA could not happen especially in a small input signal.

## 4. Conclusion

Nowadays, optical fiber is widely used in military, medical, telecommunication, networking and broadcasting industry. EDFA is used for its reliable, minimal loss, cost effective, simple and flexible in communication network. However, for enhancement of EDFA, Zirconia-EDF is used to increase the overall performance of amplifier. For this paper, we focus on short gain medium of compact devices.

Based on the gain analysis of -30 dBm input pump power, Zr-EDF shows the highest gain with increment of 8 % and 20 % compared to Bi-EDF and Si-EDF, respectively. Again, Zr-EDF leads the highest gain as increased 5 % and 36 % when input pump power at -10 dBm compared to Bi-EDF and SI-EDF. Overall noise figure of Zr-EDF is maintained below than both of other fibers.

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