# OUTPUT POWER AND EFFICIENCY IN LINEAR AND RING CONFIGURATIONS OF CONTINUOUS WAVE ERBIUM DOPED FIBER LASER

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UNIVERSITI TEKNOLOGI MALAYSIA

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Special dedicated to my parents,

Mat Yusoff Bin Ahmad & Rofiah Binti Jaafar

To my beloved siblings,

Siti Rohayu, Rahimatul Azlina, Siti Rohaiza, Marini, Ismail, Ibrahim

To my special friend,

Amin

And, my beloved Master in Science/Research friends.

Thank you for all your supports, pray, blessing and endless love!

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# ABSTRACT

Erbium doped fiber laser plays an important role in 1.5 micron wavelength region which contributes in many applications for example in communication such as erbium doped fiber amplifier and spectroscopy in medical fields. A continuous wave fiber laser operating at 1.5 micron wavelength region was demonstrated utilizing erbium doped as the gain medium in both linear and ring configurations. The output power and the efficiency of both linear and ring configurations of Erbium Doped Fiber (EDF) laser were characterised. The laser threshold and the efficiency of linear and ring configurations of EDF laser then were compared. In the linear configuration, the wavelength division multiplexing (WDM) was used and Fiber Bragg Gratings (FBGs) was inserting at both ends of the laser cavity. In the ring configuration, WDM and 3 dB output coupler are used to complete the laser cavity. The slope efficiency for the linear configuration is 0.23 % while for the ring configuration is 2.12 %. The laser threshold where the lasing occurred for linear cavity is 88.8 mW and the laser threshold for ring cavity is 40.2 mW. The maximum output power for both linear and ring configurations are 0.32 mW and 4.13 mW respectively.

# ABSTRAK

Laser gentian terdop erbium yang beroperasi dalam panjang gelobang 1.5 mikron memainkan peranan penting dalam menyumbang pelbagai aplikasi contohnya dalam komunikasi seperti penguat laser gentian erbium dan spektroskopi dalam bidang perubatan. Laser gentian gelombang berterusan yang beroperasi dalam rantau gelombang 1.5 mikron telah didemonstrasi menggunakan terdop erbium sebagai ruang penggandaan dalam kedua-dua konfigurasi iaitu linear dan lingkaran. Output kuasa yang dikeluarkan dan efisiensi laser gentian terdop erbium bagi ke dua-dua konfigurasi linear dan lingkaran dicirikan. Ambang laser dan kecekapan bagi kedua-dua konfigurasi ini kemudiannya dibandingkan. Bagi konfigurasi linear, multiplexer pembahagian panjang gelombang dan jalur gentian Bragg telah disambungkan di kedua-dua hujung rongga linear. Di dalam konfigurasi lingkaran pula, multiplexer pembahagian panjang dan penghubung output digunakan untuk melengkapkan rongga laser. Efisiensi kecerunan bagi konfigurasi linear adalah 0.23 % manakala untuk konfigurasi lingkaran adalah 2.12 %. Nilai ambang laser di mana minimum kuasa input yang diberikan untuk penghasilan laser bagi rongga linear ialah 88.8 mW manakala nilai bagi ambang laser rongga bulatan adalah 40.2 mW. Nilai kuasa output bagi konfigurasi linear dan lingkaran, masing-masing ialah 0.32 mW dan 4.13 mW.

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# LIST OF ABBREVIATION

| | | |
|---|---|---|
| ASE | - | Amplified Spontaneous Emission |
| CW | - | Continuous wave |
| EDF | - | Erbium doped fiber |
| FBG | - | Fiber Bragg grating |
| NA | - | Numerical Aperture |
| OPM | - | Optical power meter |
| OSA | - | Optical spectrum analyser |
| WDM | - | Wave division multiplexing |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $n$ | - | Refractive index |
| $n_0$ | - | Refractive index of air |
| $n_1$ | - | Refractive index of core |
| $n_0$ | - | Refractive index of cladding |
| $n_{eff}$ | - | Effective refractive index |
| $\theta_r$ | - | Reflected angle |
| $\theta_t$ | - | Transmitted angle |
| $\theta_i$ | - | Incident angle |
| $\theta_c$ | - | Critical angle |
| $\theta_a$ | - | Acceptance angle |
| $\Delta$ | - | Refractive index |
| R | - | Reflectivity |
| E | - | Energy level |
| $\lambda_B$ | - | Bragg wavelength |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Optical fiber technology has been revolutionized the communication over the past decades, especially with the rapidly growth of the internet and the increasingly high demand in bit rate. In addition optical fiber also has been used in medicine technologies because of the properties of the fiber optics have allowed medical personnel to see places in the human body with greater ease and also comfort to the patient. Fiber lasers have gained many great interest since they possess a number of physical attributes that distinguish them from other classes of lasers and that differentiate them in terms of functionality [1], performance and practically.

Fiber laser firstly invented by Elias Snitzerin in 1963 [2,3,4] and in late 1980s fiber laser devices appeared in market. The output laser was emitted a few tens milliwatts with large gain medium because the used of single mode laser diode as a pumping source in the fiber laser system.

The revolution of fiber laser was continued with the variation rare earth elements such as erbium, ytterbium, thulium and neodymium. These rare earth elements also known as gain medium which is provides the energy levels in the laser system. Erbium $Er^{3+}$ is one of the rare earth elements that have attracted many researchers to explore the characterization of this fiber laser gerating at 1.5 micron meter.

In this dissertation work, the rare earth of Erbium $Er^{3+}$is chosen to study the lasing properties at 1.5 micron meter region. This topic was chosen we want to research about the optimization of output power fiber laser based on linear and ring configuration.

## 1.2 Problem Statement

Continuous wave, single frequency lasers are required in a wide range communication, medical technologies, sensor and spectroscopic applications. In addition, with the system integration and miniaturization is being emphasized. The study about the device compatibility with fiber and optical waveguide is essential. The miniature devices, diode pump, single frequency (wavelength), narrow line width, solid state lasers are currently being commercially manufactured in varied configurations. In order to design fiber laser compatible with size and performance which is highly demand in market, studies and researches about fiber laser configurations are crucially needed. In this dissertation work, erbium doped fiber laser (EDF) is used to generate linear and ring laser cavity. This fiber configurations designs are adjusted by increasing the pump power. Hence, the efficiency and output power are measured.

## 1.3 Objectives

This study aims to achieve the objectives as listed below:

1. To characterise the output power and the efficiency of both linear and ring configurations of Erbium doped fiber laser.
2. To compare the performance of linear and ring configurations of erbium doped fiber laser.

## 1.4 Scope

The focus of this study is to compare the performance of linear and ring configuration of erbium doped fiber laser. The preparation of the erbium doped fiber for linear and ring configuration is one of the scopes of the study. Next, the fiber is tested using Optical Spectrum Analyzer. The output result from the experiment for both ring and linear configurations are analysed in order to compare the performance of different configurations erbium doped fiber laser.

## 1.5 Dissertation Layout

The dissertation consists of five chapters. Chapter one consists of a brief introduction of the laser and erbium doped fiber laser, problem statement, objectives of the study and the scope of the study. Chapter two briefs the theoretical and the literature review related to this study.

Chapter three reveals and explains the instrumentation used and the methodology conducted in this study. Chapter four contains the results, analysis and the discussion of the results. Then, chapter five concludes the experiment has successfully fulfilled the objectives of the study together with brief recommendations and suggestions for future work.

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