PARAMETER OPTIMIZATION SIMULATION OF HIGH POWER YTTERBIUM DOPED DOUBLE-CLAD FIBER LASER

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This thesis is specially dedicated to:

My beloved parents,
Maamur Othman, Zaharah Mohamad

My dear husband,
Mohd Shahrom

My supportive sibling,
Mohd Redwan, Nur Shahida

My dedicated lecturers,

and all my friends.

…….thanks…..

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ABSTRACT

The studies of ytterbium-doped double-clad fiber laser system that can be used to produce high power laser are comprehensively analyzed in this research. The simulation was done using Liekki commercial software application. The engine of this simulation application was based on rate equation which relates to the design parameter of the fiber laser. In order to improve the performance of Yb^{3+}-doped double clad fiber laser, there are several critical parameters that need to be analyzed which are pump wavelength, fiber length, pump power, dopant concentration and output reflectivity, R_2. The result shows pump wavelength of 976 nm presents the highest efficiency value of 84.58 % compared to 915 nm and 920 nm. It is found that dopant concentration of $N= 4 \times 10^{25}$ m^{-3} is the best choice to produce high output power. It is also found that the optimum fiber length for this work is 15.4 m which correspond to the output power of 39 W with forward pump power of P_p = 50 W. The optimum fiber length does not depend on the output reflectivity, R_2 when R_2 is greater than 90 %.

ABSTRAK

Kajian sistem laser gentian dua lapisan yang didopkan dengan ytterbium boleh digunakan untuk menghasilkan laser kuasa tinggi dan dianalisis secara komprehensif dalam kajian ini. Simulasi ini telah dilakukan oleh aplikasi perisian komersial Liekki. Enjin aplikasi simulasi ini adalah berdasarkan persamaan kadaran yang berkaitan untuk reka bentuk parameter laser gentian. Dalam usaha untuk memperbaiki prestasi laser gentian dua lapisan yang didopkan dengan ytterbium, terdapat beberapa parameter kritikal yang perlu dianalisis iaitu panjang gelombang pam, panjang gentian, kuasa pam, kepekatan pendopan dan output pantulan R_2. Hasil keputusan menunjukkan gelombang pum dengan nilai 976 nm menghasilkan kecekapan yang tinggi dengan nilai 84.58 % berbanding 915 nm dan 920 nm. Ia menunjukkan kuasa keluaran untuk N= 4 x 10^{25} m^{-3} adalah pilihan terbaik untuk menghasilkan kuasa keluaran yang lebih tinggi. Ia juga menunjukkan bahawa panjang gentian optimum dalam kajian ini ialah 15.4 m dengan kuasa keluaran 39 W dengan menggunakan pam kuasa kehadapan P_p = 50 W. Panjang gentian optimum tidak bergantung kepada output pantulan,R_2 apabila R_2 melebihi 90%.

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LIST OF ABBREVIATIONS

DCF	-	Double Clad Fiber
DFL	-	Doped Fiber Laser
EDFL	-	Erbium doped fiber Laser
ASE	-	Amplified Spontaneous Emission
FBG	-	Fiber Bragg Grating
WDM	-	Wavelength division multiplexing
MPC	-	Multimode pump Coupler

LIST OF SYMBOLS

Yb	-	Ytterbium
Er	-	Erbium
Nd	-	Neodynium
N	-	Dopant concentration
λ_B	-	Bragg wavelength
P_p	-	Pump Power
$P^+(z)$	-	Forward Signal Power
$P^-(z)$	-	Backward Signal Power
α_a	-	Absorption Coefficient
α_s	-	Scattering Loss Coefficient
λ_p	-	Pump Wavelength
λ_s	-	Signal Wavelength
τf	-	Spontaneous Lifetime
σs	-	Stimulated Emission Cross-Section
Af	-	Saturation Signal Output Power
ms	-	Millisecond
m	-	Meter
dB	-	Decibel
nm	-	Nanometer
kW	-	Kilowatt

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

High-power fiber laser have many advantages over other types of high power lasers including high conversion efficiency, immunity from thermal lensing effect due to large ratio of surface area to volume, no need of beam steering, simplicity of optical construction and excellent beam quality. Most work on Yb-doped fiber laser focuses on the inclusion of fiber Bragg grating (FBG) into the cavity and also the use of Yb-doped fiber with double clad structure [1]. Yb^{+3} ion have special properties among different kinds of ion such as simple energy levels, long life time at high level, high quantum efficiency and wide absorption spectrum which make it possible to develop a high-power Yb^{+3} doped fiber laser.

As the rate equation in Yb^{+3} doped double-clad fiber laser (DCFLs) is nonlinear, it is not possible to investigate the effect of difference parameter upon the laser output directly, and so the rate equation have to be solved by analytical or numerical method. To perform an optimizing design, the effect of difference factors such as pump power, dopant rate, fiber length, fiber's cross section shape and Bragg

reflector coefficient is accessible to survey and simulate in fiber laser output by solving the rate equation.

Understanding the role of thermally induces stress and others thermo-optics effect in power scaling studies requires much attentions because the standard fiber design will eventually lead to a high core temperature can no longer be justified as the thermal effect is negligible in practice. Interestingly, the recent modeling of thermal effect of glass fiber laser has been revealed where a careful management of these effects can remarkably reduced the handling of these lasers as performing scaling up effort.

1.2 Statement of Problem

There has been recent interest in the development of ytterbium-doped fiber laser system that has been used for high power laser. Moreover, strongly pumped fiber amplifiers are often been used to generate high power output by magnifying continuous wave in many applications. Ytterbium doped fiber can offer high gain, good efficiency, excellent beam quality and broad gain bandwidth.

Previously [2], erbium doped fiber amplifiers has attracted great interest in major commercial application because it can provide a very high peak power. However, the use of erbium doped fiber in telecommunication is irrelevant because of others rare earth element offers them for consideration. A new discovery of other rare earth dopant which is ytterbium doped fiber has been used mainly as laser material. This is due to their ability to provide amplification over a broad wavelength range from ~975 nm to ~1200 nm.

Recently, rare-earth doped double clad fiber laser have made considerable progress experimentally. Double-clad fiber lasers (DCFLs) were widely applied in many fields, such as medicine, military, industry and modern telecommunications. It is due to their inherent advantages over solid state lasers, such as high output power, high conversion efficiency, lower cost and excellent beam quality [3].

In this research, the simulation are conducted to analyze and optimize the amplification performance of ytterbium doped double clad fiber and determine the optimal parameter such as fiber length, dopant concentration, pump power and reflectivity.

1.3 Objective of the Study

The objectives of this study are:

i. To design and simulate of Ytterbium doped double-clad fiber laser system.
ii. To investigate the Yb-doped DCF laser parameter such as pump power, fiber length, dopant concentration and reflectivity that can lead to optimum output laser.

1.4 Scope of the Study

The scope of this study includes the understanding on the principle of fiber laser system. This study will discuss the concept of pumping process of rare earth element which is ytterbium doped in fiber laser system. Besides that, this study is done to investigate the dynamic characteristic of laser and optimize the system

parameter such as dopant concentration of Yb, fiber length, pump power, and reflectivity for practical application.

1.5 Significance of the study

Among several laser which is doped with rare-earth elements, Ytterbium-doped double clad fiber (DCF) laser will be focused in this research and the effect of some parameter to the output power of Yb-doped DCF will be determined. This result will proved that the Yb-doped DCF laser can offer high output power compared to the other rare-earth element and it is highly dependent on the fiber laser parameter such as fiber length, dopant concentration, pump power, pumping scheme, and reflectivity. Thus, this research is done to investigate the Yb-doped DCF laser parameter that can lead to optimum output laser. Besides, this research can briefly review on the rate equation fiber laser system. This is very important in order to understand the basic principle of Yb-doped DCF laser system.

1.6 Thesis plan

This thesis describes how to design and simulate fiber laser parameter of Yb-doped DCF laser. This thesis has been divided into five main chapters. Chapter 1 covers the introduction part which is including general background of study and some reviews from previous research and describes the problem statements which lead to this research, the objectives, scope and the significance of study. Chapter 2 will describe all the literature reviews, latest issue and some of theories regarding on Yb-doped DCF laser system. The theories describes including the physical properties, the principle of fiber laser system and the rate equation. Chapter 3 which

is research methodology will explains all the simulation procedure by using Liekki Application Designer (LAD) software including the numerical setup. The simulation results and discussion on this research will be analyzed and explains in details in Chapter 4. Finally, Chapter 5 summarizes all the simulation findings and concludes all the results and some suggestions for future studies related to this research. The flow chart of the research activities is shown in Figure 1.1.

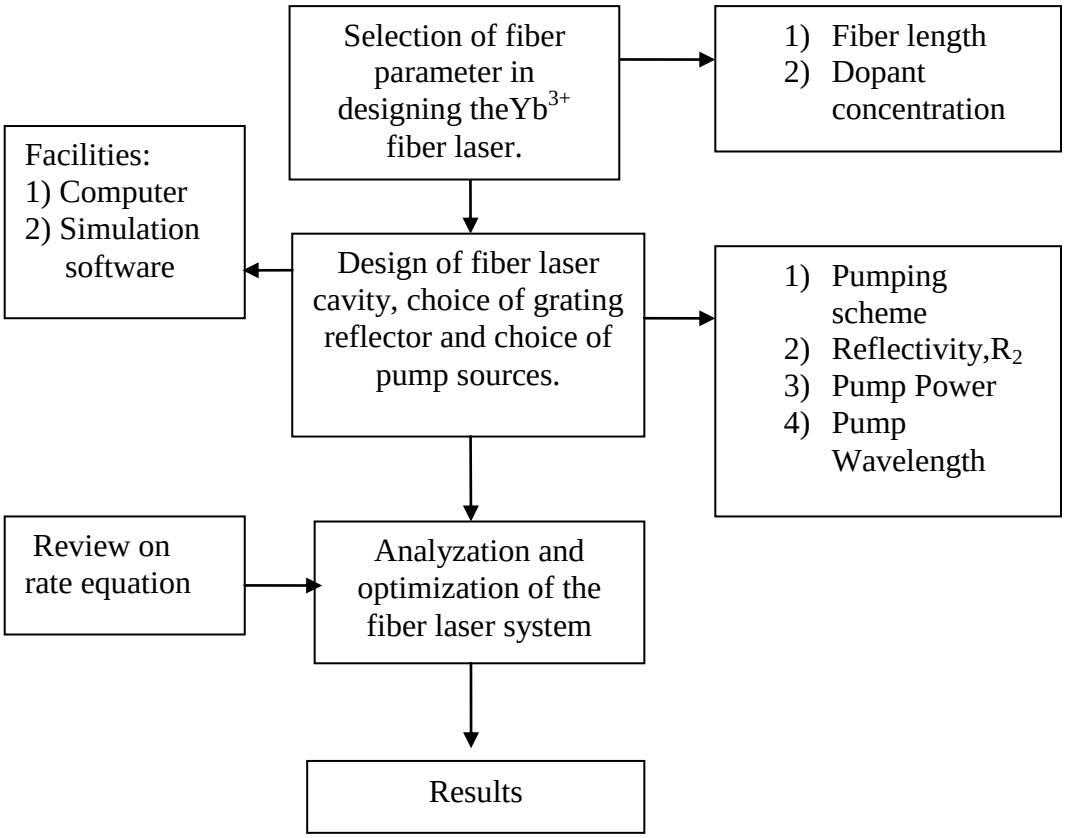

Figure 1.1: Flow chart of research activities.

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