UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF A NOVEL TUNABLE ERBIUM-DOPED FIBER LASER

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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In the name of God, Most Gracious, Most Merciful

Dedication to

My parents and all of my family members

Abstract of thesis presented to the Senate of University Putra Malaysia in Fulfilment of the requirements for the degree of Master of Science

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Chairman : Associate Professor Mohd Khazani Abdullah, Ph.D.

Faculty :Engineering

Widely tunable single channel fiber lasers operating in the 1550nm wavelength region are needed as laser source for applications such as wavelength-division-multiplexed (WDM) communication systems, fiber sensors, spectroscopy, and optical fiber gyroscopes.

Fiber lasers are emerging as an attractive alternative technology for wavelength-selectable WDM source for direct compatibility with fiber-optic transmission medium, excellent amplifying properties of rare-earth doped fibers, rapidly continuing progress in novel fiber gain media, maturity and robustness of the laser diode pumps used, and availability of fiber-based components.

The tunable laser applications of interest in this work have distinct performance requirement, which is the need for wide tunability (the ability to tune the lasing emission through a wide range of wavelengths).

In this thesis, the design and development of a single channel continuous wave erbium-doped fiber laser (EDFL), with novel loop mirror configuration, is experimentally studied. Based on design parameters of a fiber laser (launched pump powers, erbium-doped fiber lengths and output reflectivities of fiber laser), three fiber laser configurations; backward, forward, and bi-directional pumping are demonstrated. Throughout this work different lengths of erbium-doped fiber with various output reflectivities have been examined to extract the optimum output performance of a fiber laser. The performance of the fiber laser is presented in terms of threshold pump power, slope of efficiency, output peak power, linewidth, tuning range, and side mode suppression ratio (SMSR). This new fiber loop configuration exhibits considerably high performance. Output power of 27.7 mW and efficient noise suppression of more than 70 dB have been achieved. A threshold power as low as 2.5 mW and slope efficiency of 20% is realized. Narrow spectral width of 0.058nm over a tuning range of 40 nm is obtained.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

REKABENTUK DAN PEMBINAAN NOBEL UNTUK GENTIAN LASER BOLEH TALA TERDOP ERBIUM BOLEH TALA

Oleh

MOHAMMED ALFAYTURI S. HOWIEG

Mei 2003

Pengerusi : Associate Professor Mohd Khazani Abdullah, Ph.D.

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Laser boleh tala beroperasi dalam julat gelombang 1550 nm dan diperlukan dalam aplikasi seperti sistem komunikasi pemultipleks bahagi jarak gelombang (WDM), sensor gentian optik, spektroskopi dan giroskop gentian optik.

Laser gentian kini muncul sebagai teknologi alternatif untuk sistem WDM jarak gelombang terpilih kerana keserasiannya sebagai punca cahaya untuk gentian optik. Selain dari faktor keserasian, keupayaan gentian optik jenis bumi nadir untuk mengamplifikasikan isyarat kecil, keteguhan/kelasakan pam diod laser dan ketersediaan komponen asas gentian optik merupakan beberapa faktor lain yang menyebabkan laser gentian mula mendapat perhatian.

Laser boleh tala yang diselidiki memerlukan keperluan prestasi yang berbeza dari laser biasa iaitu ia memerlukan laser ini ditala pada jarak gelombang yang lebar.

Dalam tesis ini, rekabentuk dan pembangunan laser gelombang selanjar konfigurasi unggul yang didopan menggunakan bahan Erbium dengan keluaran saluran tunggal akan dikaji.

Berdasarkan parameter rekabentuk laser gentian iaitu kuasa masukan pam, panjang gentian optik dopan Erbium dan nisbah kuasa keluaran laser gentian, tiga jenis konfigurasi akan dikaji iaitu konfigurasi laser dengan pam kehadapan, kebelakang dan kedua-dua arah pam. Di dalam ujikaji menggunakan konfigurasi yang dinyatakan, panjang gentian optik Erbium yang berbeza dengan nisbah keluaran kuasa yang berbeza akan dikaji bagi mencapai prestasi (nilai ambang pam, kecekapan laser, keluaran kuasa puncak, garis lebar, julat jarak gelombang dan SMSR) laser gentian yang terbaik.

Konfigurasi laser gentian yang dihasilkan mempunyai nilai keluaran kuasa sebanyak 27.7 mW dan kecekapan SMSR lebih dari 70 dB. Nilai ambang untuk penghasilan laser serendah 2.5 mW dengan kecekapan 20% disamping lebar garis 0.058 nm bagi jarak tala 40 nm telah diperolehi.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACS	-	Absorption Cross-Section
ASE	-	Amplified Spontaneous Emission
BPF	-	Band Pass Filter
CW	-	Continuous Wave
ECS	-	Emission Cross-Section
EDF	-	Erbium Doped Fiber
EDFL	-	Erbium Doped Fiber Laser
ESA	-	Excited State Absorption
FBG	-	Fiber Bragg Grating
FP	-	Fabry-Perot
FWHM	-	Full Width Half Maximum
GSA	-	Ground State Absorption
LDM	-	Laser Diode Module
LED	-	Laser Emitting Diode
MOPA	-	Master-Oscillator Power-Amplifier
NA	-	Numerical Aperture
OSA	-	Optical Spectrum Analyzer
RIN	-	Relative Intensity Noise
SLM	-	Single-longitudinal Mode
SMF	-	Single Mode Fiber
SMSR	-	Side Mode Suppression Ratio

TBPF	-	Tunable Band Pass Filter
WDM	-	Wavelength Division Multiplexing

CHAPTER 1

INTRODUCTION

1.1 Background

Optical fiber communications are systems that employ optical wave as information carrier and optical fiber as information transmission line. In theory the greater the carrier frequency, the larger the available transmission bandwidth and thus the information-carrying capacity of the communication systems. Such a system at optical frequencies offers an increase in the potential usable bandwidth by a factor of 103 over traditional microwave transmission [Li Wei, 2000]. The proposal for optical communication via optical fibers was made almost simultaneously in 1966 by kao and Hockham and Werts. It is obvious that the suitable optical source and the optical fiber are the key elements for the development of optical fiber communication. Although, previously the availability of laser sources had stimulated research into optical fiber communication, optical fiber communication was not considered to be practical until 1970, when optical fiber technology had advanced to a point where the fiber with loss of 0.2 dB/km or less was achieved [Kapron, Keck, and Maurer, 1970]. Since then, silica fiber and optoelectronics including laser sources have been the subject of large-scale world wide research and product development. As a result, optical fiber communication is established today as one of the most promising technologies within the area of short and long distance data transmissions [Green, 1993 and Arieli, 2003].

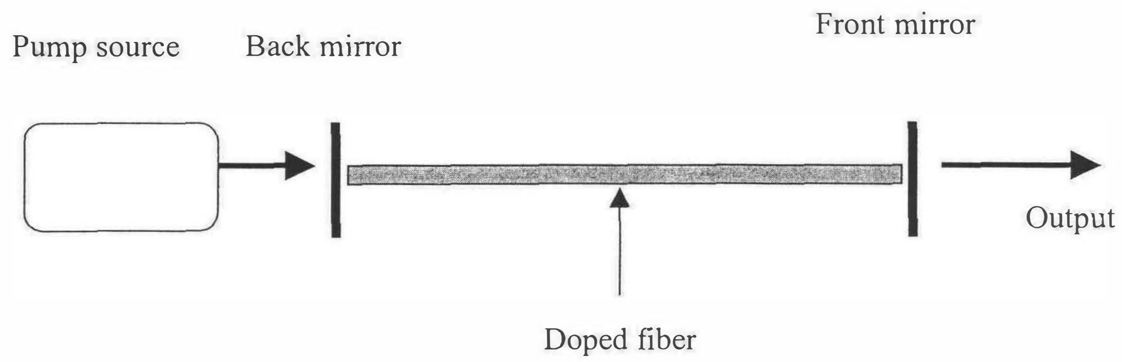
The development of technology in optical fiber communication system has passed through a few distinct stages to increase the capacity of the optical systems. It is found that the ultimate capacity is determined by the quality of the optical source and the fiber [Agrawal, 1992]. The optical source has advanced from broad-spectrum LEDs to multi-mode laser diodes and then to single-mode laser diodes.

The progress in the optical source plays a very important rule in minimizing the dispersion, a major factor limiting the performance. For example, a laser source with a very narrow linewidth would be very desirable; Fiber lasers have the potential of being an excellent candidate as a source in optical communication systems [Mizrahi and Digiovanni 1993, Zyskind and Sulhoff 1993]. Compared to the laser diode, whose linewidths are limited by the short cavity length. A fiber laser [Lee, 1998 and Gloag, 1996] could have a much narrower linewidth. A linewidth as narrow as 0.95 kHz was obtained in fiber laser [Gloa, 1996]. Moreover, fiber lasers are the most natural source for fiber-optic communications, since the light is already in the fiber and they can be directly spliced to the systems.

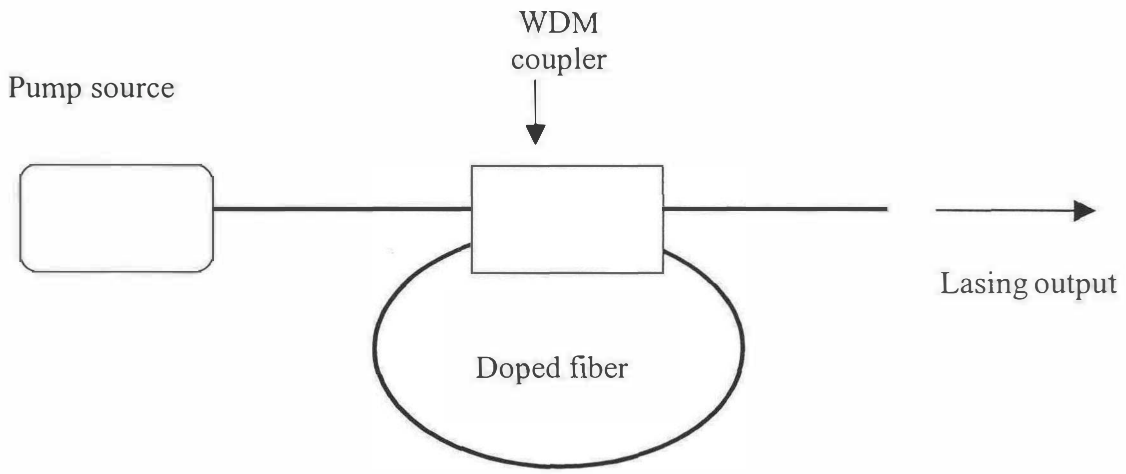
1.2 What is a Fiber Laser

A fiber laser is a laser system, which uses a piece of specially doped fiber as the active medium. Different types of dopants in different host materials give different characteristics of the laser system [Abdullah, 1999]. Silica is the most popular material as a host while fluoride is also being used for different purposes. Rare earth ions such as erbium and ytterbium are the most widely used dopants to emit signals at 1550nm and 1310nm wavelengths respectively. The principles behind a fiber laser are the same as in any other solid-state lasers, with amplification accruing via stimulated emission. In common with other lasers it has a non-linear output power with respect to the pump power. Below the threshold pump power where the gain is the same as the cavity loss, the output from the device is incoherent and composed mainly of spontaneous emission. At pump power greater than this, the gain remains clamped at the cavity loss with the output from the device being contained in a narrower bandwidth of coherent radiation. Above threshold, the output power normally has a linear yield with respect to pump power. It is useful to define a parameter termed as slope efficiency of the laser, η_s, which is given by the expression $\eta_s = \Delta Pout / \Delta Ppump$ where $\Delta Pout$ is the change in output power for the change of pump power of $\Delta Ppump$ when the laser is operating above threshold.

Fiber lasers can generally be designed in two configurations that are the Fabry-Perot or rectilinear configuration and the ring configuration [Abdullah, 1999]. Figure 1.1 shows the schematics of the two configurations. In this study fiber loop back mirror linear cavity configuration is employed as the fiber laser design.



(a)



(b)

Figure 1.1: Fiber laser configurations, (a) Fabry-Perot or linear cavity, (b) ring cavity