UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF A MULTI-WAVELENGTH BRILLOUIN/ERBIUM LONG-BAND FABRY PEROT FIBER LASER

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By

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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 wife, my daughters, my brothers and sisters

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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Faculty: Engineering

Multi-wavelength fiber lasers operating in the long-wavelength band (L-band) wavelength region are needed as laser source for applications such as wavelength-division-multiplexed (WDM) communication systems, fiber sensors, spectroscopy and optical fiber gyroscopes.

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

The multi-wavelength laser applications of interest to this work have distinct performance requirement. This requirement 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 multi channel continuous wave Brillouin/ Erbium L-band fiber laser (BEFL), with novel loop mirror configuration, has been studied experimentally. The design parameters of multi-wavelength fiber laser (launched pump powers, single mode optical fiber lengths and Brillouin wavelengths), the multi wavelength Brillouin/erbium linear fiber laser configuration with bi-directional pumping is demonstrated. Throughout this work different lengths of single mode optical fiber with various launched pump powers and Brillouin wavelengths have been examined to extract the optimum output performance of a BEFL. The performance of the BEFL is presented in terms of threshold pump power, output peak power, tuning range and the number of Stokes. This development fiber loop configuration exhibits considerably high performance. Twenty-four of Stokes with 10 nm tuning range and efficient output powers were obtained.

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

REKABENTUK DAN PEMBANGUNAN JARAK GELOMBANG-MULTI BRILLOUIN/ERBIUM FABRY PEROT FIBER LASER

Oleh

TARAK ALI HADDUD

Mei 2004

Pengerusi : Professor Madya Mohd Adzir Mahdi, Ph.D.

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Laser Jarak Gelombang –Berbilang Fiber yang beroperasi pada kawasan jarak gelombang jalur jarak gelombang panjang (jalur-L) diperlukan sebagai sumber laser untuk aplikasi-aplikasi seperti sistem komunikasi pemultipleks bahagi jarak gelombang(WDM), deria fiber, spektroskopi dan fiber gyroscopes optikal.

Laser fiber jarak gelombang-multi sedang bangkit sebagai daya tarikan teknologi alternatif untuk pilihan-jarak gelombang WDM. Ia menjadi sumber yang sesuai bagi perantraan transmisi fiber optik, ciri penguat terbaik bagi fiber terdop jarang-bumi, perolehan Brillouin, kesinambungan kemajuan yang pantas dalam media perolehan fiber novel, pengunaan kematangan dan keteguhan pam laser diod and komponen berasaskan fiber yang sedia ada.

Keperluan aplikasi laser jarak gelombang-berbilang dalam hasil kerja ini mempunyai keperluan prestasi yang jelas. Keperluan ini adalah untuk talaan lebar (keupayaan mentala pancaran laser jarak gelombang pada jarak yang lebar).

Dalam tesis ini, rekabentuk dan pembangunan kesinambungan gelombang Brillouin Saluran berbilang/laser fiber Erbium jalur-L (BEFL), beserta konfigurasi cermin gelung

novel, telah dikaji secara eksperimen. Rekabentuk parameter bagi laser fiber jarak gelombang berbilang(kuasa pam yang dilancarkan, mod berasingan jarak optikal fiber dan jarak gelombang Brillouin), konfigurasi jarak gelomabang Brillouin/ laser fiber erbium lurus bersama pengepaman dua-arah telah ditunjukkan. Melalui hasil kerja ini optikal fiber mode berasingan yang mempunyai jarak yang berbeza berserta keperlbagaian kuasa pam yang dilancarkan dan jarak gelombang Brillouin telah diperiksa untuk mendapatkan output prestasi yang optimum bagi BEFL. Prestasi BEFL dipersembahkan dalam bentuk ambang kuasa pam, kuasa puncak output, jarak talaan dan bilangan Stokes. Konfigurasi pembangunan gelung fiber menghasilkan prestasi yang agak tinggi. Dua puluh empat Stokes yang mempunyai jarak talaan 10nm dan kuasa output yang efektif diperolehi

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LIST OF ABBREVIATIONS

Bp	Brillouin Pump
DFB	Distributed Feed-Back
λB	Brillouin Wavelength
CW	Continuous Wave
EDF	Erbium Doped Fiber
EDFL	Erbium Doped Fiber Laser
ESA	Excited State Absorption
FBG	Fiber Bragg Grating
FP	Fabry-Perot
FWM	Four-Wave Multiplexed
LED	Laser Emitting Diode
OSA	Optical Spectrum Analyzer
SBS	Stimulated Brillouin Scattering
SMF	Single Mode Fiber
TLS	Tunable Laser Source
WDM	Wavelength Division Multiplexing
Pp	980 nm Pump Power

CHAPTER 1

INTRODUCTION

1.1 Multi Wavelength Fiber Lasers Background

The light is widely used to transmit information over large distance because of its security, reliability and huge bandwidth. One of the most important devices in optical communication systems is laser source. It is used to launch light into fibers. There are many types of laser that can be used for optical communication systems. In general, fiber lasers have many advantages over other types of lasers. When compared to many solid-state and gas laser systems; fiber lasers have high output power, simpler, more compact and can be pumped with laser diodes. Moreover, when compared to laser diodes, fiber lasers are spectrally cleaner and can be modulated with less chirp and signal distortion. Also, the intense pumping availability in rare-earth doped, single mode fibers lead to lower threshold three-level laser operation, and improve efficiency, just as tighter confinement improves laser diode performance [Li, 2000].

In addition, fiber-to-fiber compatibility is a distinct advantage in optical communication systems [Talaverano, 2001]. However, the multiple wavelength laser sources with narrow wavelength channel spacing are of high potential for use in dense wavelength division multiplexing (DWDM) transmission systems. As optical transmission system capacity of optical communication system approaching a few Terabit per second through DWDM technique, multi wavelength source technology becomes more important [Krauss, 2002]. Much effort has been focused to achieve simultaneous multi wavelength operation. The use of erbium-doped fiber laser (EDFL) has been demonstrated to achieve multiple wavelength outputs [Yamashita, 1996]. The selection of their operation wavelengths has been achieved by using different methods; see more explanation in Chapter 2.

1.2 Hybrid Brillouin/Erbium Fiber Lasers

A general technique for producing a Brillouin fiber laser is to construct a critically coupled fiber resonator, which is necessary because of the small magnitude of the Brillouin gain [Agrawal, 1995]. The disadvantage of the critically coupled Brillouin fiber lasers presented in the small output power that can be achieved [Hill, 76], the requirement of cavity matching to the pump signal, and the difficulty in incorporating intra-cavity elements because of their associated loss. This type of laser can be compared with erbium-doped fiber lasers, which operate with a high-gain medium that allows for efficient operation of complex resonator structures. These EDFL's are suited for operation with large output coupling, and can have an operating quantum efficiency of >95% [Cowle, 1991].

The problem for a critically coupled resonator in a laser based on Brillouin gain can be overcome by using an erbium-doped fiber amplifier to compensate for the resonator losses while still originating lasing action from the Brillouin gain. The wavelength of the resulting laser is accurately determined by both; the BEFL cavity resonances and the wavelength of the Brillouin pump. Therefore, the exact frequency of the BEFL lasing is not completely controlled by the injected Brillouin pump, but can be derived from the position of the BEFL cavity resonance [Stepanov, 1997], and a large number of channels can be achieved.

1.3 Uses and Merits

The multi-wavelength fiber lasers technology are well suited to industrial applications because they are compact and reliable. They have many applications such as sources for DWDM systems, sensor; laser gyroscopes [Zarinetchi, 1991] and current monitors [Kung, 1996].

Other possible applications for the BEFL are optical-fiber characterization [Ohashi, 1992], narrow-band width amplification [Ferreira, 1994], distributed strain and temperature measurement [Tateda, 1990 & Kurashima, 1990], fiber frequency shifter [Kalli, 1991] pulse generation [Guy, 1995] and microwave-frequency generation [Culverhouse, 1991]. The multi-wavelength fiber laser systems investigated can be used as an optical source to upgrade information carrying capacity of the communication systems, to meeting the fast development of WDM technology.

1.4 Problem Statement and Motivation

The researchers continue their efforts toward the development multi-wavelength laser sources. Moreover, producing more number of channels in a laser system is more economical. The multi-wavelength lasers used today still suffering from the high cost and complex structure. Then, the motivation of this thesis is to search for economic source to produce multi-channels. The Brillouin/Erbium fiber laser (BEFL) using Fabry-Perot cavity and operates in the L-band region is used for this thesis. The principles of BEFL system are based on rare earth active material (erbium doped-fiber), primary laser source (laser diode), non linear Brillouin scattering (SMF), and feedback mechanism (loop fiber mirror).

1.5 Research Objectives

The research work concentrates on the design, development and testing of Brillouin/Erbium fiber laser system. Thus, the key objectives of the research work are as the following:

1) To investigate the behaviors of stimulated Brillouin scattering in single mode fibers.
2) To develop a multi-wavelength Brillouin/Erbium fiber laser using Fabry-Perot cavity, in L-band region.
3) To the performance of the developed fiber laser based on the number of Stokes.

1.6 Organization of the Thesis

This thesis presents the design and development of multi wavelength Brillouin/Erbium fiber laser (BEFL). The fiber Fabry Perot resonator is used to construct BEFL. The work is divided into several chapters. A short introduction is given in Chapter 1. The background of Erbium fiber laser, Brillouin fiber laser and multi wavelength fiber laser with emphasis on multi-wavelength Brillouin/Erbium fiber lasers (BEFL) is presented in Chapter 2. Multi wavelength Brillouin/erbium fiber lasers can be designed with a variety of cavity configurations; the two most common are explained in this chapter. Chapter 3 will first come out with simple sketch to explain the effect of SMF length on output and threshold power. Then, it goes on to describe the related fiber laser components, in order to have a better understanding of the construction of the BEFL. A system configuration, which is Brillouin/Erbium fiber loop mirror with two circulators on both of its ends as loop back reflectors will be presented. This will allow bi-directional operation in the cavity to be obtained without the use of optical isolators. Chapter 4 presents the implementation of the Brillouin/Erbium fiber lasers, based on the resonator proposed in Chapter 3. The experimental results of the BEFL including the output power, threshold, and the number of Stokes will be presented in this Chapter. The thesis concludes with Chapter 5, which summarizes the work done on Brillouin/Erbium fiber laser, loop mirror configuration and the optimization of the performance parameters for this configuration. Recommendations and suggestions for future works will be treated here.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The concept of fiber laser is not new, but it is a surprising idea. The theoretical concept behind fiber-laser operation is quite elegant. An optical fiber doped with a lasing material is optically pumped by laser pump source (flash lamp or laser diode), and a laser output is obtained from the fiber. This output laser can be varied according to the type of pump source, the length of the active materials and some other parameters.

This chapter gives background information on Erbium–doped fiber and Brillouin effect in SMF. Then, it reviews the general multi wavelength fiber lasers, with some emphasis on the Brillouin/Erbium fiber lasers.

2.2 Background of Erbium-Doped Fiber Lasers.

Among rare-earth doped fiber lasers, erbium-doped fiber lasers at 1.5 μm region attracts the most attention because it coincides with the least-loss (as low as 0.2 dB/Km [Kapron, 1970]) region of silica fibers used for light wave communications. Erbium-doped fiber lasers can be operated either in continuous wave or in pulse mode. Continuous wave EDFLs are preferred for applications in multi-channel system, while pulsed mode EDFLs performs better in Soliton communication systems. The techniques of Q-switching and mode locking [Huang, 2000] can be used to produce high power short duration pulses, which is beyond the scope of this thesis.

2.3 Brillouin Fiber-Background

While studying the types of light scattering, emphasis will be on Brillouin scattering that has relation with the objective of this work.

2.3.1 Scattering of Light

When light travels through a transparent media, most part of it travels in a straight line in direction of propgation, other than a small fraction of it that will be scattered. The inhomogeneities (heterogeneity) of refractive index of the media are responsible for this phenomenon. In addition, there are two more important reasons for this phenomenon, Rayleigh and Brillouin effects.

2.3.2 Rayleigh Effect

It is related to the inhomogeneities due to the material structure. Air and glass are well known examples where the small refractive index fluctuations induced by their amorphous nature can scatter light in all directions [Palais, 1998]. This is done without changing the frequency of the scattered light; because the inhomogeneities are frozen in the material structure, see Figure 2.1

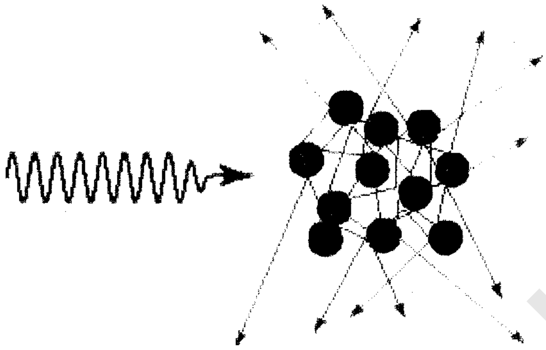

Figure 2.1: Light Scattering Without Change in Frequency (Rayleigh Effect).

2.3.3 Brillouin Effect

French physicist Léon Brillouin was the first to study the diffusion of light by acoustic waves in 1920. One of the distinctive features he observed was a change of frequency in the scattered light. This effect, named after its discoverer, has remained for a long time within the frame of purely academic research. But it went out of the lab shortly after the advent of lasers and optical fibers. Its first "contribution" was indeed a negative one: it was demonstrated that the Brillouin effect is the most drastic limitation encountered when the light power within the fiber is increased. In other words, there is a power threshold above which any additional light is back scattered due to its interaction with acoustic waves. Since a few years, a handful of research groups have been trying to convert this flaw - the relatively high efficiency of the Brillouin scattering in fibers - into an advantage in developing multi wavelength fiber lasers.