UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF SEMICONDUCTOR BASED AND FIBER LASER BASED OPTICAL TRANSMITTER

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By

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Abstract of the thesis presented to the Senate of University Putra Malaysia in partial fulfillment of the requirement for the degree of Master of Science

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January 2003

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

Faculty: **Engineering**

This thesis presents the research works on development, characterization, application and analysis of semiconductor based and fiber laser based optical transmitter.

Semiconductor laser is the most widely used in the optical communication system. This is mainly because of the compact size, weight and simplicity of modulation scheme. Laser diode is used in developing the optical transmitter and the application in the optical communication. The function of the optical transmitter is to convert the electric signal into optical signal and thus the optical transmitter is also called Electric to optical (E/O) converter.

There are two approaches used in this thesis: simulation and experiment. Simulation is designed to check and determine the functionality of the designed circuit.

Efforts, costs and time can be saved through the software simulation process, which are the benefits that makes the simulation as an absolute option in the circuit designing.

Experiment is implemented after the simulated circuit works. However, the result in the experiment is slightly different with the result of simulation. This is due to the ideal environmental in simulation while in the experiment, there are many sources of losses occurred.

The maximum optical power of the optical transmitter was 1.07 mW with support bandwidth is 240 Mbps at 1312 nm center wavelength. SMSR of laser spectrum was 58.12 dB with spectral width of 0.016 nm.

However, there are some limitations of semiconductor laser which gives rise to the need for a search new alternative of developing light source. Fiber laser seems an optimum alternative used a light source due to the high peak performance semiconductor and wide tuning range compared to specific wavelength of the laser diode.

The design and development of fiber laser is viewed particularly from the engineering perspective. Two host materials were used in the study, Bismuth and Silica. The highest power of Si-EDFL was 2.75 mW with 61.63 dB SMSR while for the Bi-EDFL the peak power was 0.669 mW with 57.3 dB SMSR. It is showed that Bismuth based fiber has show good performance even with very short length. Both of host materials ware achieved 35 nm tuning range.

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

REKACIPTA PENGHANTAR OPTIK BERASASKAN SEMIKONDUKTOR DAN GENTIAN LASER

Oleh

NORHANA BINTI ARSAD

Januari 2003

Pengerusi: **Prof Madya Mohd Khazani Abdullah, Ph.D.**

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Tesis ini mempamerkan penyelidikan pada rekacipta, pembangunan, ciri-ciri, aplikasi dan analisis bagi penghantar optik dengan menggunakan laser semikonduktor dan laser gentian.

Laser semikonduktor banyak digunakan sebagai sumber cahaya dalam sistem optik. Ini adalah kerana saiznya yang kecil dan ringan serta modulasi yang ringkas. Contoh laser semikonduktor ialah diod laser dan diod pancaran cahaya. Pelaksanaan penghantar optik dengan menggunakan diod laser merangkumi keseluruhan pembangunan penghantar optik dan aplikasinya dalam sistem rangkaian optik. Diod laser berfungsi menukar isyarat dimana arus elektrik akan ditukarkan kepada cahaya. Oleh itu, ia juga dikenali sebagai penukar electrik kepada cahaya (E/O).

Dua pendekatan telah digunakan dalam tesis ini iaitu simulasi dan ujikaji. Simulasi bertujuan untuk memeriksa dan menentukan fungsi sebenar bagi litar yang direka. Usaha, kos dan masa yang boleh dijimatkan melalui proses perisian simulasi

adalah antara kelebihan yang menjadikan simulasi sebagai satu pilihan dalam merekabentuk litar.

Ekperimen dilaksanakan selepas litar simulasi berfungsi, bagaimanapun keputusan dalam ekperimen mempunyai sedikit perbezaan dengan keputusan simulasi. Ini adalah disebabkan persekitaran yang ideal dalam simulasi manakala kehilangan kuasa berlaku dalam ekperimen.

Kuasa maximum bagi penghantar optik ialah 1.07 mW dengan lebarjalur yang disokong ialah 240 Mbps pada panjang gelombang 1312 nm. SMSR bagi spectrum laser ialah 58.12 dB dengan lebar spectra 0.016 nm.

Walaubagaimanapun laser semikonduktor mempunyai bebarapa kelemahan yang mencetuskan idea bagi pencarian alternatif baru dalam membangunkan sumber cahaya. Laser gentian dilihat sebagai alternatif optimum digunakan sebagai sumber cahaya kerana mempunyai tahap kuasa yang lebih tinggi serta julat panjang gelombang yang lebar berbanding diod laser yang mempunyai panjang gelombang yang khusus. Bagi laser yang lain seperti laser mainframe, saiz dan penyelenggaraan yang rumit menyebabkannya kurang berpontensi untuk menggantikan laser semikonduktor.

Rekabentuk dan pembangunan laser gentian dilihat dari segi kejuruteraan. Dua bahan hos yang dikaji ialah Bismuth dan Silica. Kuasa paling tinggi yang diperolehi bagi Si-EDFL ialah 2.75 mW dengan SMSR 61.63 dB manakala kuasa tertinggi bagi Bi-EDFL ialah 0.669 mW dengan SMSR 57.3 dB. Ia menunjukkan Bismuth mempunyai

persembahan yang baik walaupun mempunyai kepanjang yang jauh pendek dari Silica. Julat talaan bagi kedua-dua bahan hos ini ialah 35 nm.

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I certify that an Examination Committee met on 3rd January 2003 to conduct the final examination of Norhana Binti Arsad on her Master of Science thesis entitled "Design and Development of Semiconductor Based and Fiber Laser Based Optical Transmitter" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

NORHANA BINTI ARSAD

Date: 22/1/2003

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LIST OF ABBREVIATIONS

AC	-	Alternative Current
ASE	-	Amplified Spontaneous Emission
ATM	-	Asynchronous Transfer Mode
Bi-EDF	-	Bismuth-Based Erbium Doped Fiber
Bi-EDFL	-	Bismuth-Based Erbium Doped Fiber Laser
BNC	-	Bayonet Neil-Concelman/British Naval Connector
CH	-	Channel
dB	-	Decibel
DBR	-	Distributed-Bragg Reflector
DC	-	Direct Current
DFB	-	Distributed- Feedback
DWDM	-	Dense Wavelength Division Multiplexing
E/O	-	Electric To Optical
EDF	-	Erbium Doped Fiber
EDFL	-	Erbium Doped Fiber Laser
ESA	-	Excited State Absorption
FDDI	-	Fiber Distributed Data Interface
FP	-	Fabry Perot
FPGA	-	Field Programmable Gate Arrays
FTTH	-	Fiber To The Home

FWHM	-	Full Width Half Maximum
Gbps	-	Giga Bits Per Second
ITU	-	International Telecommunication Union
ITU-T	-	International Telecommunication Union – Telecommunication Standards Sector
LAN	-	Local Area Network
LD	-	Laser Diode
LED	-	Light Emitting Diode
L-I	-	Light- Current
NRZ	-	Non Return To Zero
O/E	-	Optical To Electric
OC	-	Optical Carrier
OSA	-	Optical Spectrum Analyzer
PCB	-	Printed Circuit Board
PD	-	Photodiode
RJ11	-	Register Jack 11
RJ45	-	Register Jack 45
RZ	-	Return To Zero
SDH	-	Synchronous Digital Hierarchy
Si-EDFL	-	Silica-Based Erbium Doped Fiber Laser
SMSR	-	Side Mode Suppression Ratio
SNR	-	Signal To Noise Ratio
SNR	-	Signal To Noise Ratio

STM-1	-	Synchronous Transfer Mode 1
TE	-	Transverse Electric
TM	-	Transverse Magnetic
TTL	-	Transistor - Transistor Logic
UPM	-	University Putra Malaysia
VCSEL	-	Vertical Cavity Surface Emitting Light
WAN	-	Wide Area Network
WDM	-	Wavelength Division Multiplexing

LIST OF NOTATIONS

λ	-	Wavelength
τ	-	Rise Time
α	-	Effective Absorption Coefficient
Γ	-	Optical Confinement Factor
Ω	-	ohm
λc	-	Wavelength Center
$\Delta \lambda$	-	Spectral width
C	-	Capacitor
C_{EL2075}	-	Elantec Amplifier Capacitance
E	-	Energy Level
h	-	Planck's Constant (6.626×10^{-34})
I	-	Optical Field Density
I_b	-	Base Current
I_c	-	Collector Current
In	-	Log_n
I_{TH}	-	Current Threshold
L	-	Cavity Length
n	-	Refractive Index
P	-	Optical Power
R	-	Resistor

t_d	-	Modulation Rate
v	-	Velocity of light (2.998×10^8)
V_b	-	Base Voltage
V_{be}	-	Base-Emitter Voltage
V_c	-	Collector Voltage

CHAPTER 1

INTRODUCTION

1.1 Background

An optical communication system is similar in basic concept to any type of communication system, the function of which is to convey the signal from the information source over transmission medium to the destination. Optical communication network therefore consists of a transmitter or modulator linked to the information source, fiber as the transmission medium, and a receiver or demodulator at the destination point.

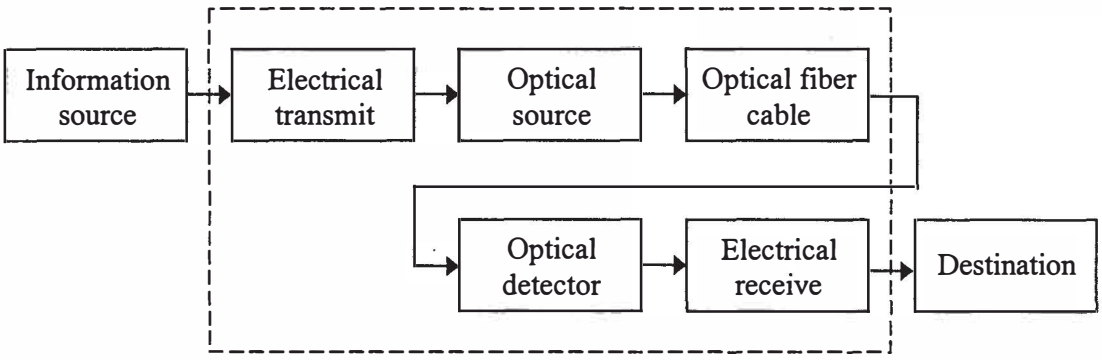

Figure 1.1 Optical Communication System

For optical communication system (as shown in Figure 1.1), the information sources provide an electrical signal to transmitter comprising an electrical stage, which drives an optical source to modulate of the lightwave carrier. The optical source, which provides the electrical – optical conversion, may be either a

semiconductor laser or light emitting diode (LED). In today's communication, the Laser Diodes (LDs) are used in long haul systems, while the LEDs are used for short distance communications (Senior, 1992).

This project focuses on the transmitter side of the system, where a transmitter based on LED and LD is built as well as a light source based on fiber laser.

1.2 Problem Statement

The conventional transmitters employed in fiber optics system are based on semiconductor devices in the form of LED for short distance and LD for long distances. LD is more advantageous in that it can support higher bandwidth as well. Thus, it is very important to develop expertise in controlling LED and LD in the form of a complete transmitter. The lack of skill in Malaysia local industries in this aspect is obvious from the fact that essentially all transmitters are imported such as Finisar and Hewlett Packard. The expertise in designing and developing an optical transmitter is vital in order to fully understand the issues in optical fiber transmissions.

Nevertheless, it is also understood that the existing transmitter technology has its limitations. For example, LD cannot be easily tuned over a broad spectral range. The temperature sensitive LD structure also tends to limit its optical output power. Higher output requires higher injected current, which in turns increases the temperature and affects the stability. The fabrication process of an LD is also complicated and requires high skill and specialized environment. Thus, a new light