MODELING AND THEORETICAL STUDIES OF SEMICONDUCTOR LASER DIODE

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DISSERTATION SUBMITTED IN FULFILMENT
OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE

FACULTY OF SCIENCE
UNIVERSITY OF MALAYA
KUALA LUMPUR
2005

Abstract

Driven by the recent development of Vertical-Cavity Surface-Emitting Lasers (VCSELs) technology, the modeling and theoretical studies of semiconductor laser based on VCSELs diode operating at 1.55 μm wavelength for long-distance optical communication is carried out. Modeling and simulation for the DBR mirror and active region of the VCSELs components using HS_Design are performed followed by a complete VCSELs device characteristic simulation using LaserMOD. A comparison between three types of DBR mirror of InGaAsP/InP, GaAs/AlGaAs and SiC/MgO shows that the GaAs/AlGaAs system exhibits the highest reflectivity with 99.9% and 99.7% for n- and p-DBR mirror respectively. The VCSELs active region consists of eight quantum wells with 1% compressive strain recorded the highest optical gain around 1.55 μm for the active region simulation. From these results, a complete VCSELs diode employing 41.5 periods of GaAs/$Al_{0.72}Ga_{0.28}As$ n-DBR mirror and 33.5 periods of GaAs/$Al_{0.74}Ga_{0.26}As$ p-DBR mirror wafer-fused to InGaAsP active region is proposed for device characteristics simulation. The mode analysis shows that the fundamental optical mode is overlapping the active region. A symmetric and circular emitted beam with a small beam divergence of 2^0 is observed from the near-field and far-field characterization, resulting in high coupling efficiency to optical fibers. The simulated PL spectra and optical spectrum exhibits lasing wavelength at 1.55 μm with single longitudinal mode operation. The proposed 1.55 μm VCSELs diode demonstrated a threshold current of 1.05 mA corresponding to a threshold current density of 1.53 kA/cm^2, 0.56 of differential quantum efficiency with 0.28 power conversion efficiency, voltage threshold of 0.95 V, turn-on voltage of 0.8 V and DBR series resistance of 143 Ω.

Abstrak

Dengan kemajuan pesat dan terkini yang ditunjukkan oleh teknologi Vertical-Cavity Surface-Emitting Lasers (VCSELs), pembinaan model dan kajian teoritikal semikonduktor laser berdasarkan diod VCSELs dengan operasi panjang gelombang 1.55 μm untuk komunikasi optik jarak jauh telah dijalankan. Model dan simulasi komponen VCSELs seperti cermin DBR dan kawasan aktif dilakukan dengan HS_Design dengan diikuti simulasi sifat peranti bagi diod VCSELs yang lengkap menggunakan LaserMOD. Perbandingan antara tiga jenis cermin DBR iaitu InGaAsP/InP, GaAs/AlGaAs dan SiC/MgO menunjukkan sistem GaAs/AlGaAs menghasilkan pantulan tertinggi sebanyak 99.9% dan 99.7% bagi cermin n- dan p-DBR. Kawasan aktif VCSELs yang terdiri daripada lapan telaga kuantum dengan pemampatan tekanan sebanyak 1% mencatatkan peningkatan optik tertinggi sekitar 1.55 μm untuk simulasi kawasan aktif. Berdasarkan keputusan ini, diod VCSELs yang lengkap terdiri daripada 41.5 tempoh bagi GaAs/$Al_{0.72}Ga_{0.28}As$ cermin n-DBR dan 33.5 tempoh bagi GaAs/$Al_{0.74}Ga_{0.26}As$ cermin p-DBR dengan dicantumkan pada kawasan aktif InGaAsP dicadangan untuk simulasi sifat peranti. Analisis mod menunjukkan pertindihan mod optikal asas dengan kawasan aktif. Bim laser yang dipancarkan adalah simetri dan berbentuk bulat dengan perkembangan bim sekecil 2^0 diperhatikan daripada pencirian medan-dekat dan medan-jauh, menunjukkan pekali penggabungan yang tinggi kepada fiber optik. Simulasi PL dan spektrum optikal menunjukkan panjang gelombang laser pada 1.55 μm dengan operasi mod tunggal terhasil. Diod 1.55 μm VCSELs yang dicadangkan mempunyai arus kritikal pada 1.05 mA, merujuk kepada ketumpatan arus kritikal 1.53 kA/cm^2, 0.56 pekali perbezaan kuantum dengan 0.28 pekali penukaran kuasa, voltan kritikal pada 0.95 V, voltan peningkatan pada 0.8 V dan rintangan sesiri DBR sebanyak 143 Ω.

Acknowledgement

The realization of this work would not have been possible without the help and support from a number of people and sectors. I certainly realize that it is nearly impossible to grant everyone, but it would not be right to acknowledge a few names only, just because that makes it easier for me.

My foremost and greatest appreciation goes to my supervisor, Assoc. Prof. Dr. Burhanuddin Kamaluddin. His knowledge, passion and understanding always inspire me. I am truly grateful for his guidance. Indebted acknowledgement is given to Prof. Muhamad Rasat Muhamad, who indirectly supervised and advised me. His motivation, support and recommendation have opened-up many opportunities for me such as research funding, research network and sending me to various conferences for presenting my work. In addition, I would like to thank Prof. Alias Daud and Assoc. Prof. Saadah Abdul Rahman for their general advice and support given.

I wish to thank University Malaya for supporting the early stage of my research work through the tutorship and Vot F funding. Highest acknowledgement is given to Ministry of Science, Technology & Innovation (MOSTI) for the National Scientific Fellowship (NSF) scholarship awarded. I am also grateful to the MOSTI through the Intensification of Research Priority Area (IRPA) grant for sponsoring my research presentation in various conferences. I am very grateful that my final research stage is made possible with the technical support from Telekom Research & Development. Indebted appreciation is mentioned for Dr. Abd. Aziz Mat Hassan, Dr. Mohd Salleh Deni and Dr. Abd. Fatah Awang Mat, who are all my superiors at my current work in Telekom Research & Development for their understanding.

I am also grateful to the Solid State Research Laboratory staff and graduate students – En. Md. Salleh, En. Mohamed Arof, Lim Chui Huah, Hung Yew Mun, Suffian Mitani, Ngah Ramzi, Lee Hock Guan, Mat Nor, Khairul Anuar, Roszairi, Richard, Goh Boon Tong, Kamal Harmoza, and Naharuddin for the technical discussion and amusing coffee-breaks, as well as the friendship offered.

Finally, I would like to contribute this hard work to my family especially to my parents for their infinite love, support, motivation and understanding. I must dedicate a special part for Zalifah Ismail for the companionship during those long hours of simulation, support, understanding, patience and the most important her never-ending love throughout the years.

List of Publications

1. M. Sharizal, B. Kamaluddin, & M. R. Muhamad, "Mode Analysis of Long-Wavelength Vertical-Cavity Surface-Emitting Lasers Diode," *Proc. of 2004 IEEE International Conf. of Semiconductor Electronics*, pp. 407-410, Mines Dec. 7-9, 2004.

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List of Abbreviations

1D	One-Dimensional
2D	Two-Dimensional
3D	Three-Dimensional
Al_2O_3	Alumina Oxide
AlAs	Aluminum Arsenide
AlAsSb	Aluminum Arsenide Antimony
AlGaAs	Aluminum Gallium Arsenide
AlGaAsSb	Aluminum Gallium Arsenide Antimony
AlGaInAs	Aluminum Gallium Indium Arsenide
AlGaN	Aluminum Gallium Nitride
AlInAs	Aluminum Indium Arsenide
AlInGaAs	Aluminum Indium Gallium Arsenide
a-Si	Amorphous Silica
CD	Compact Disc
CO_2	Carbon Dioxide
CW	Continuous Wave
DBR	Distributed Bragg Reflector
DFB	Distributed Feedback
DH	Double Heterojunction
DSM	Dynamic Single Mode
EDFA	Erbium Doped Fiber Amplifiers
EELs	Edge-Emitting Lasers
FTTH	Fiber-to-the-House
GaAs	Gallium Arsenide
GaAsSb	Gallium Arsenide Antimony
GaInAsSb	Gallium Indium Arsenide Antimony
GaInNAs	Gallium Indium Nitride Arsenide
GaInNAs	Gallium Indium Nitride Arsenide
GaN	Gallium Nitride
GSMBE	Gas-source Molecular Beam Epitaxy
InAlGaP	Indium Aluminum Gallium Phosphide
InGaAs	Indium Gallium Arsenide
InGaAsP	Indium Gallium Arsenide Phosphide
InGaN	Indium Gallium Nitride
InP	Indium Phosphide
IR	Infra-Red
KP	Kronnig-Penney
LED	Light Emitting Diode
L-I	Light-Current
L-I-V	Light-Current-Voltage
LO	Longitudinal Optical
MBE	Molecular Beam Epitaxy
MgO	Magnesium Oxide
MOCVD	Metal-organic Chemical Vapor Deposition
MQW	Multi Quantum Well
PbSeTe	Lead Selenium Tellurium
PbSnSeTe	Lead Tin Selenium Tellurium
PCM	Pulse-Code-Modulated
PECVD	Plasma-enhanced Chemical-Vapor Deposition
PL	Photoluminescence

QW	Quantum Well
SELs	Surface-Emitting Lasers
SiC	Silica Carbide
SiO_2	Silica Dioxide
SRH	Shockley-Read-Hall
TE	Transverse Electric
TM	Transverse Magnetic
TMM	Transfer Matrix Method
VCD	Video Compact Disc
VCSELs	Vertical-Cavity Surface-Emitting Lasers
V-I	Voltage-Current
WDM	Wavelength-Division Multiplexing
ZnCdSe	Zinc Cadmium Selenium
ZnSe	Zinc Selenium