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# **MODELING AND THEORETICAL STUDIES OF SEMICONDUCTOR LASER DIODE**

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## 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  $\mu\text{m}$  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  $\mu\text{m}$  for the active region simulation. From these results, a complete VCSELs diode employing 41.5 periods of GaAs/Al<sub>0.72</sub>Ga<sub>0.28</sub>As n-DBR mirror and 33.5 periods of GaAs/Al<sub>0.74</sub>Ga<sub>0.26</sub>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  $2^\circ$  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  $\mu\text{m}$  with single longitudinal mode operation. The proposed 1.55  $\mu\text{m}$  VCSELs diode demonstrated a threshold current of 1.05 mA corresponding to a threshold current density of 1.53  $\text{kA}/\text{cm}^2$ , 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  $\Omega$ .

## 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  $1.55\text{ }\mu\text{m}$  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  $1.55\text{ }\mu\text{m}$  untuk simulasi kawasan aktif. Berdasarkan keputusan ini, diod VCSELs yang lengkap terdiri daripada 41.5 tempoh bagi GaAs/Al<sub>0.72</sub>Ga<sub>0.28</sub>As cermin n-DBR dan 33.5 tempoh bagi GaAs/Al<sub>0.74</sub>Ga<sub>0.26</sub>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  $1.55\text{ }\mu\text{m}$  dengan operasi mod tunggal terhasil. Diod  $1.55\text{ }\mu\text{m}$  VCSELs yang dicadangkan mempunyai arus kritikal pada 1.05 mA, merujuk kepada ketumpatan arus kritikal  $1.53\text{ kA/cm}^2$ , 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  $143\text{ }\Omega$ .

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## List of Publications

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3. M. Sharizal, B. Kamaluddin, & M. R. Muhamad, "Modeling of Long-wavelength VCSELs with Wafer Fusion DBR mirror," *Proc. of 2004 IEEE-LEOS Malaysian Conf. Photonics*, pp. 74-78, Selangor, Sept. 30, 2004.
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## List of Abbreviations

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

<b>QW</b>	Quantum Well
<b>SELs</b>	Surface-Emitting Lasers
<b>SiC</b>	Silica Carbide
<b>SiO<sub>2</sub></b>	Silica Dioxide
<b>SRH</b>	Shockley-Read-Hall
<b>TE</b>	Transverse Electric
<b>TM</b>	Transverse Magnetic
<b>TMM</b>	Transfer Matrix Method
<b>VCD</b>	Video Compact Disc
<b>VCSELs</b>	Vertical-Cavity Surface-Emitting Lasers
<b>V-I</b>	Voltage-Current
<b>WDM</b>	Wavelength-Division Multiplexing
<b>ZnCdSe</b>	Zinc Cadmium Selenium
<b>ZnSe</b>	Zinc Selenium