LEHIGH UNIVERSITY

Center for Optical Technologies

1550-nm GaAsSb-(In)GaAsN Type-II Quantum Wells Lasers

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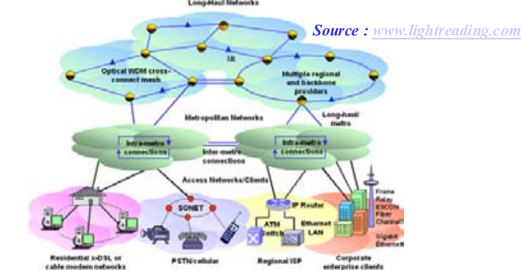
Optical Communication Networks – The Market



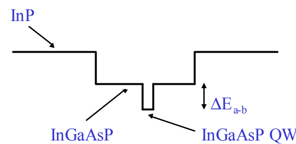
Long Haul Communication Networks

- 1550-nm VCSELs/DFBs
- Allow transmission ridges in the minimum absorption band of the fiber

Conventional Approach: to utilize InP-based Laser

→ Alternative Approach→ 1550-nm Lasers on GaAs

Conventional 1550-nm Lasers by InGaAs(P)/InP QW



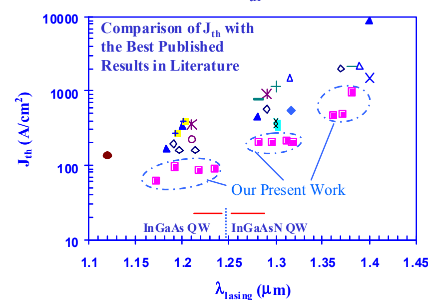
- ***Extremely Temperature Sensitive (Low T_o value)***
  - Small conduction band offset
  - Large Auger recombination
  - Intervalence band absorption (IVBA)
  - Temperature dependency of material gain (g_o)
- ***High Cost*** → for thermal management
- ***Poor InP-based VCSELs*** **Performances**
  - Lack of Materials for DBRs on InP-based VCSELs

Active Regions for Long-Wavelength Lasers on GaAs [5]

- **Conventional Approach → InGaAlAs-InGaAsP/InP**
  - **Poor T_0 values & Low Material Gain**
  - **Difficult to Realize VCSELs**
- **1300-nm Diode Lasers on GaAs**
  - **InGaAsN QW → *Excellent Candidate*** [1]
- **1550-nm Diode Lasers on GaAs**
  - **→Have to offer *Superior Performances***
  - **→No QW candidates provides superior results *yet*** [2,3,4]

1. N. Tansu, N. J. Kirsch, and L. J. Mawst, Appl. Phys. Lett., vol. 81(14), September 2002.
2. M. O. Fischer, M. Reinhardt, and A. Forchel, IEEE Select. J. Quantum. Electron., 7(2), pp. 149-151, 2001.
3. W. Ha, V. Gambin, S. Bank, M. Wistey, H. Yuen, S. Kim, J. S. Harris, Jr., IEEE J. Quantum. Electron., vol. 38(9), pp. 1260-1267, 2002.
4. P. Dowd, W. Braun, D. J. Smith, C. M. Ryu, C.-Z. Guo, S. L. Chen, U. Koelle, S. R. Johnson, and Y.-H. Zhang, Appl. Phys. Lett., 75 (9), pp. 1267-1269, 1999.
5. N. Tansu, and L. J. Mawst, IEEE J. Quantum. Electron., vol. 39 (10), October 2003

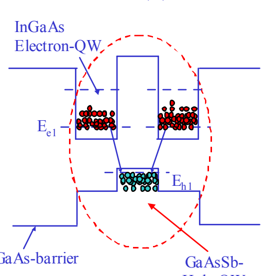
Room Temperature J_{th} vs. λ comparison [1]



InGaAsN QW Lasers
Low J_{th} at 1310-nm regime
but J_{th} ↑ as λ ↑

1. Nelson Tansu, Jeng-Ya Yeh, and Luke J. Mawst → Our Present Work

GaAsSb(P)-InGaAs Type II QW Lasers [1] - I



Γ_{e_hh}~ 37.6 % for λ=1357-nm
No Lasers at λ = 1500-nm

- ***GaAsSb(P) & InGaAs → Highly Strained Materials***
- ***Carrier Leakage in Hole-QW, ΔE_v ~ 165 meV***

1. P. Dowd, W. Braun, D. J. Smith, C. M. Ryu, C.-Z. Guo, S. L. Chen, U. Koelle, S. R. Johnson, and Y.-H. Zhang, Appl. Phys. Lett., 75 (9), pp. 1267-1269, 1999.

Approaches for 1550-nm Lasers on GaAs [4]

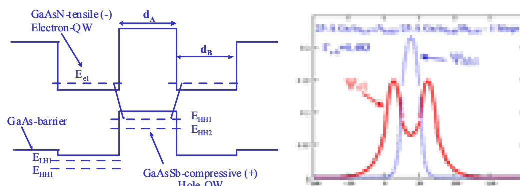
Type I QW
- **InGaAsN QW** [1] → Difficult to Push to 1550-nm
- **InGaAsNSb QW** [2]
  - Promising Approach
  - Extremely high strain & still immature

Type II QW
- **GaAsSb(P)-InGaAs QW** [3]

Type I QD
- **In(Ga)As QD** → Large strain limits the max λ

1. M. O. Fischer, M. Reinhardt, and A. Forchel, IEEE Select. J. Quantum. Electron., 7(2), pp. 149-151, 2001.
2. W. Ha, V. Gambin, S. Bank, M. Wistey, H. Yuen, S. Kim, J. S. Harris, Jr., IEEE J. Quantum. Electron., vol. 38(9), pp. 1260-1267, 2002.
3. P. Dowd, W. Braun, D. J. Smith, C. M. Ryu, C.-Z. Guo, S. L. Chen, U. Koelle, S. R. Johnson, and Y.-H. Zhang, Appl. Phys. Lett., 75 (9), pp. 1267-1269, 1999.
4. N. Tansu, and L. J. Mawst, IEEE J. Quantum. Electron., vol. 39 (10), October 2003.

GaAsSb-(In)GaAsN Type-II SQW Lasers [1]

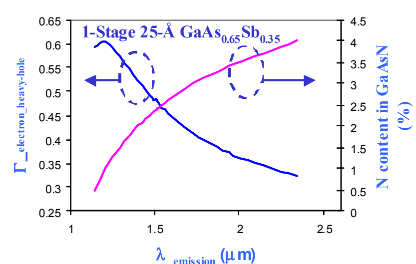


Single-Stage Region

- **GaAsSb & (In)GaAsN → Reduced Net Strain**
  - **$\Gamma_{e\text{-}h}$ ~ 49 %**
- **Excellent Carrier Confinement → ΔE_v ~ 260 meV**

1. N. Tansu, and L. J. Mawst, IEEE J. Quantum. Electron., vol. 39 (10), October 2003.

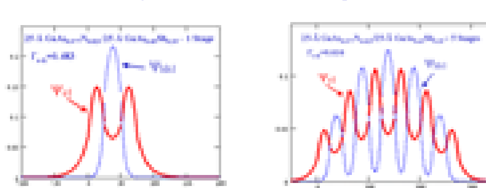
GaAsSb-(In)GaAsN Type-II SQW Lasers [1]



- **Reasonably-Large Overlap for ψ_e and ψ_{hh}**
  - **$\Gamma_{e\text{-}h}$ ~ 49 % for 1500-nm, N ~ 2.5 %**
  - **$\Gamma_{e\text{-}h}$ ~ 35 % for 2000-nm, N ~ 3.5 %**

1. N. Tansu, and L. J. Mawst, IEEE J. Quantum. Electron., vol. 39 (10), October 2003.

Increasing the Wavefunction Overlap: MQWs [1]

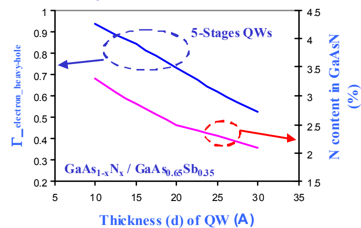


Single-QW Stage → **Multiple-QWs Stage**

- **Multiple-QW Design → Increase Wavefunction Overlap**
  - **$|\Gamma_{e\text{-}hl}|^2$ (5-QWs) ~ 65 % larger than $|\Gamma_{e\text{-}hl}|^2$ (1-QW)**

1. N. Tansu, and L. J. Mawst, IEEE J. Quantum. Electron., vol. 39 (10), October 2003.

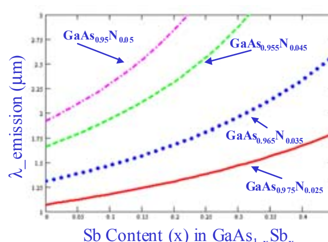
Reducing d_{QW} to Increase Coupling for 1500-nm [1]



- **Reducing the d_{QW} → Increase Wavefunction Overlap**
  - **$|\Gamma_{e\text{-}hl}|^2$ (d_{QW}=15-Å) ~ 77 % larger than $|\Gamma_{e\text{-}hl}|^2$ (d_{QW}=25-Å)**

1. N. Tansu, and L. J. Mawst, IEEE J. Quantum. Electron., vol. 39 (10), October 2003.

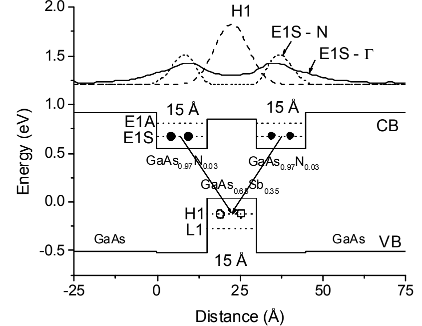
GaAsSb-(In)GaAsN Type-II SQW Lasers [1,2]



- **Potentially for Achieving up to λ=2-3 μm**

1. N. Tansu, and L. J. Mawst, IEEE J. Quantum. Electron., vol. 39 (10), October 2003.

GaAsSb-(In)GaAsN Type-II SQW Lasers [1,2]



Optical Gain for GaAsSb-(In)GaAsN Type-II QW Lasers
- **Calculated with 10 band *k.p* formalism** [2]

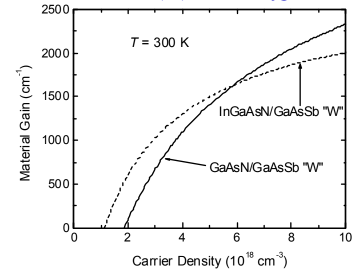
1. N. Tansu, and L. J. Mawst, IEEE J. Quantum. Electron., vol. 39 (10), October 2003.
2. I. Vurgaftmann, J. R. Meyer, N. Tansu, and L. J. Mawst, Appl. Phys. Lett., vol. 83(14), October 2003.

Calculating Band Structure: Methods

*10-band **k·p** method:*

- Augment standard 8-band ***k·p*** basis with dilute-N bands using band-anticrossing model **(BAC)** ***[Wu et al., Semicond. Sci. Tech. 17, 860 (2002)]*:**
  - **2 bands for heavy holes**
  - **2 bands for light holes**
  - **2 bands for split-off holes**
  - **2 bands for electrons**
  - **2 bands for N states**
- Diagonalize resulting SL Hamiltonian in **reciprocal space** using $0.2(2\pi/a)$ **wavevector** cutoff in order to avoid spurious states
- Calculate dispersions and corresponding matrix elements, use standard gain/spontaneous emission formalism to derive optical properties
- For gain calculations, assume that N-like components of wavefunctions **do not contribute** to optical transitions (localized in InAsN)

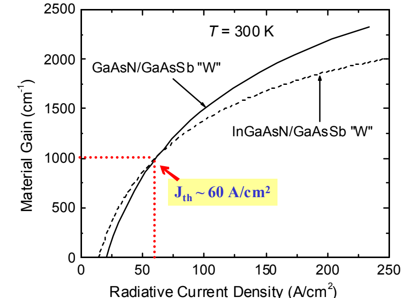
Optical Gain of GaAsSb-(In)GaAsN Type-II SQW Lasers [1]



Reasonable N_{QW} and dg/dn for Lasing Operations
- **N_{tr} ~ 1.2-1.8 x 10^{18} cm^{-3},**
- **N_{th} ~ 3 x 10^{18} cm^{-3} for g_{th} = 1000 cm^{-1}**
- **dg/dn ~ 6.5-8 x 10^{-16} cm^2**

1. I. Vurgaftmann, J. R. Meyer, N. Tansu, and L. J. Mawst, Appl. Phys. Lett., vol. 83(14), October 2003.

Optical Gain of GaAsSb-(In)GaAsN Type-II SQW Lasers [1]



Reasonable J_{tr} and J_{th} for Lasing Operations
- **J_{tr} ~ 15-20 A/cm², J_{th} ~ 60 A/cm² for g_{th} = 1000 cm^{-1}**

1. I. Vurgaftmann, J. R. Meyer, N. Tansu, and L. J. Mawst, Appl. Phys. Lett., vol. 83(14), October 2003.

GaAsSb-(In)GaAsN Type-II QW Lasers

- Novel Proposal of GaAsSb-(In)GaAsN Type-II QW Lasers
  - Potential for achieving λ = 1100-nm up to 2500-nm
- Low Net Strain for GaAsSb-(In)GaAsN
  - Strain Compensation
  - Improved Surface Morphology
  - Ease in implementation for MQW
- Reasonably-Large Optical Gain → for type-II QW
  - Low N_{tr} and N_{th}
  - Low J_{th_spon} and J_{tr_spon}
  - Reasonable High dg/dn and g_{oN}