Intersubband Electroluminescence from GaN/Al$_x$Ga$_{1-x}$N Quantum Cascade Emitter

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Motivation

• Quantum Cascade (QC) Structures
  • Utilizing quantum wells for intersubband transitions
  • Broadband capabilities
  • Better temperature performance

• III-Nitride based materials
  • Larger conduction band offsets: ~2eV
  • Better broadband capabilities than conventional QC materials
  • Capability to reach short wavelengths (<4µm) and Terahertz region (>20µm)

• EL demonstrated in GaN/AlGaN multi-quantum well structures
  • EL measured at 80K
  • Interest to demonstrate EL at higher temperatures

Design

- GaN/Al\textsubscript{0.65}Ga\textsubscript{0.35}N structures on sapphire substrate
- Simulated roughness estimated at 4Å
Design

- 4.4 / 6.6 / 4.4 / 6.4 / 4.4 / 6.6 / 4.6 / 6.8 / 4.4 / 6.8 / 4.8 / 10.2 / 3.8 / 6.8 / 4.0 / 6.6 / 4.2 / 6.6 monolayers
- 1.8 x 10^{18} \text{ cm}^{-3} \text{ doping where underlined}
Electroluminescence (EL) at 80K

- First detected at 80K
- Normalized with respect to blackbody radiation
IV Characteristics

- Pulsed IV
- Small variations among different temperatures
EL at higher temperatures

- Pulsed IV suggests probable EL at higher temperatures
- Challenge - increased noise due to higher heat generation
- Take average of 3 measurements
- All spectra normalized with respect to blackbody radiation
  - Peak at 1000 cm$^{-1}$
Electroluminescence at higher temperatures

TS13082B2 120K Normalized Spectra

- TM
- TE

Signal (a.u.) vs. Wavenumber (cm$^{-1}$)
Electroluminescence at higher temperatures

TS13082B2 160K Normalized Spectra

- **TM**
- **TE**

[Graph showing signal vs. wavenumber with two lines representing TM and TE]
Electroluminescence at higher temperatures

TS13082B2 200K Normalized Spectra

- Signal (a.u.)
- Wavenumber (cm⁻¹)
Electroluminescence at higher temperatures
Electroluminescence at higher temperatures

TS13082B2 300K Normalized Spectra

Signal (a.u.)

Wavenumber (cm$^{-1}$)
Observations

- EL signal becomes less prominent as temperature increases
  - Increased blackbody radiation due to heat
  - Increased noise
  - Signal is weak but consistent
- Two peaks
  - Blackbody radiation, centered at 1000 cm\(^{-1}\)
  - Second peak, present only in TM-polarized spectra, at 2200 cm\(^{-1}\)
    - Difference in TM- and TE-polarized spectra confirms the ISB nature of signal
  - EL signal peak (~5µm) matches prediction from design
Detector Capabilities

- When un-biased, device functions as a QC detector
Detector Capabilities

- When un-biased, device functions as a QC detector
- Absorption peak matches ISB EL signal peak
Detector Capabilities

- Continuous-wave dark IV measurement
- Responsivity: 43µA/W
Future Steps

• Optimization
  • Fabrication in progress of more QC devices
    • Same structure design, different doping levels and templates
• Demonstration of EL in shorter wavelengths
  • New design to have intersubband EL at < 4µm
• Improve temperature performance