Short wavelength intersubband emission from GaN/AlN quantum wells

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Outline

Motivations for III-nitride based ISB devices

Short-wavelength ISB emission from GaN/AlN QWs
  - Resonant second harmonic generation in GaN/AlN QWs
  - ISB emission at 2.1-2.3 µm from GaN/AlN QWs

Towards Quantum Fountain Lasers

Conclusions and prospects
Properties of nitride heterostructures

- Large conduction band offset: 1.75eV for GaN/AlN
- Direct gaps
- Remote lateral valleys (>2eV)
- Huge internal field (3-10 MV/cm)
- Electron effective mass
  \( 0.2m_0 = 3 \text{ times that of GaAs} \)
Nitride unipolar devices

Ultrafast ISB all-optical gates
Absorption recovery time 150-400 fs @ 1.5 µm

N. Iizuka et al., JAP 99, 093107 (2006); Optics Express 2006

Fast quantum well photodetector (QWIPs)


Multi-GHz electro-optical modulators based on coupled quantum wells

L. Nevou et al., APL 90, 223511 (2007)

No emitting devices have been demonstrated up to recently!
Emission at 1μm through resonant second-harmonic generation

200 GaN/AlN QWs
2.6 nm well thickness

- Generation of radiation at 1 μm wavelength
- Large double-resonance enhancement

Observation of ISB luminescence is a challenging task because the ISB luminescence efficiency is very small.

- Radiative time in the nanosecond range (~20-30 ns)
- Non-radiative time in the 0.1-0.4 picosecond range
Samples for ISB luminescence

Plasma-assisted MBE:
E. Monroy et al. CEA-Grenoble

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<tr>
<th>E900</th>
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ISB spectroscopy

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T = 300 K

\( e_1-e_2 \) absorption (Brewster's angle) \( e_1-e_3 \) absorption (multipass waveguide)

ISB luminescence

T = 300 K

E900

E1000

p-polarized excitation @ 0.98 µm in resonance with $e_1e_3$ ISB absorption

Emission strongly p-polarized

Record short emission wavelength 2.13 µm

300 K!

ISB luminescence excitation spectroscopy

- ISB luminescence excitation spectrum at 300 K obtained by tuning the Ti:Sapphire laser wavelength
- The ISB emission follows the $e_1e_3$ pump absorption for p-polarized excitation
- External efficiency 10 pW/Watt of pump power
- Internal quantum efficiency 0.3 $\mu$W/Watt of pump power

$L.\,\text{Nevou et al., APL 90, 121106 (2007)}$
Is population inversion achievable?

Condition for population inversion: $\tau_{21} < \tau_{32}$
Towards 1.5 µm ISB lasers

Quantum Fountain scheme: Coupled quantum wells provide room for population inversion and adjustment of pump/laser wavelength.

- Pump @ 1.3 µm
- Emission @ 1.5 µm

Stimulated gain 50 cm\(^{-1}\) achievable (OPO pump laser)
Evidence of strong electronic coupling

Observation of $e_1e_2$ absorption is a signature of strongly coupled wells.

The coupling vanishes for >4 ML thick AlN barriers.

Excellent agreement with simulations assuming a potential drop at the interfaces spread over 1 ML

*M. Tchernycheva et al., APL 88, 153113 (2006)*
Loss measurements on nitride waveguides

Loss measurements on nitride waveguides @ 1.5 µm: 4 cm⁻¹ for TM polarization << estimated gain

A. Lupu et al.
Conclusion:

• Resonant enhancement of SHG in GaN/AlN at 1µm
• Demonstration of room temperature ISB emission at record short wavelength of 2.1µm
• Towards QFL at 1.5µm:
  • Coupled QWs provide gain = 50 cm\(^{-1}\)
  • Propagation losses in waveguide = 4 cm\(^{-1}\)

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