# Short wavelength intersubband emission from GaN/AlN quantum wells

**Laurent Nevou**, **F. H. Julien, M. Tchernycheva,**
*OptoGaN Dept., Institut d'Electronique Fondamentale, UMR CNRS 8622, University Paris-Sud XI, Orsay, France*
*and*
**F. Guillot, E. Monroy**
*CEA-Grenoble, DRFMC/SP2M/PSC, Grenoble, France*

UNIVERSITÉ PARIS-SUD 11

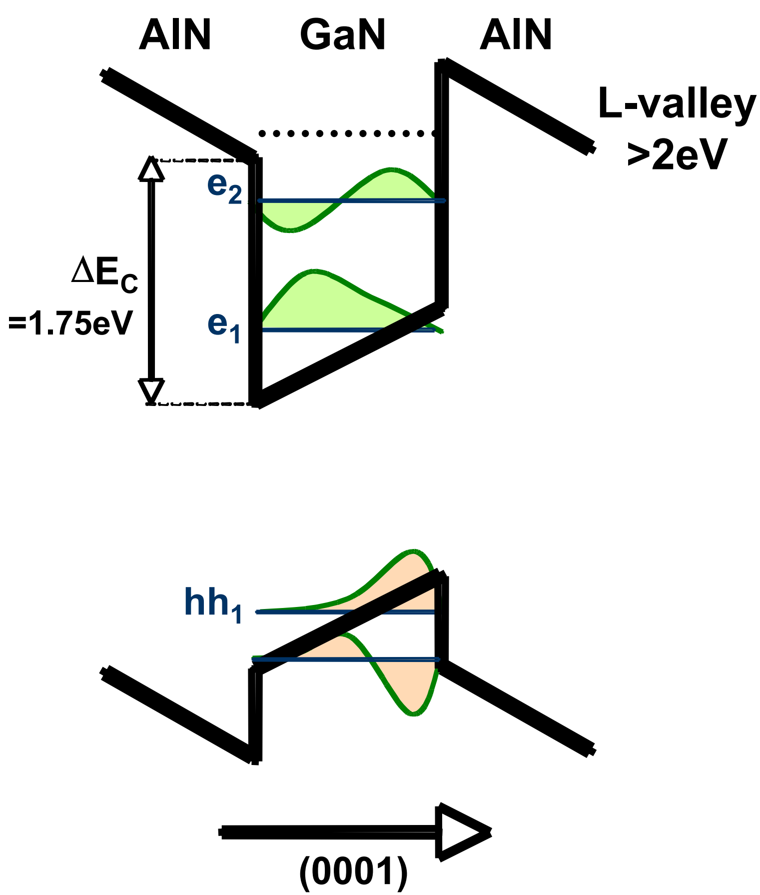
NitWave

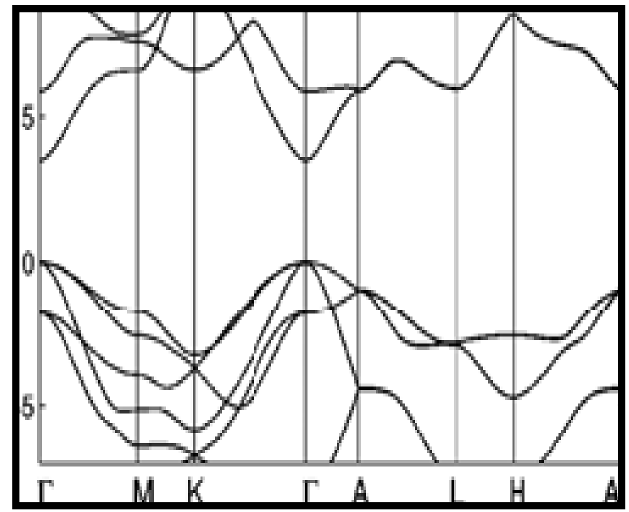
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

# 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



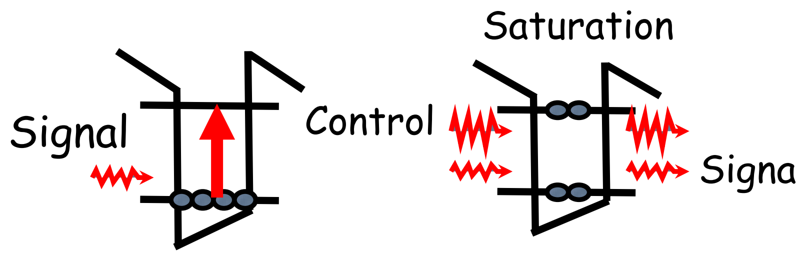




- Large conduction band offset : 1.75eV for GaN/AlN
- Direct gaps
- Remote lateral valleys (>2eV)
- Huge internal field (3-10 MV/cm)
- Electron effective mass ($0.2m_0$ = 3 times that of GaAs)

# Nitride unipolar devices

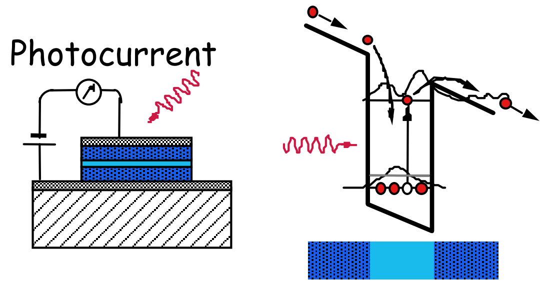
Ultrafast ISB all-optical gates
Absorption recovery time 150-400 fs @ 1.5 μm

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



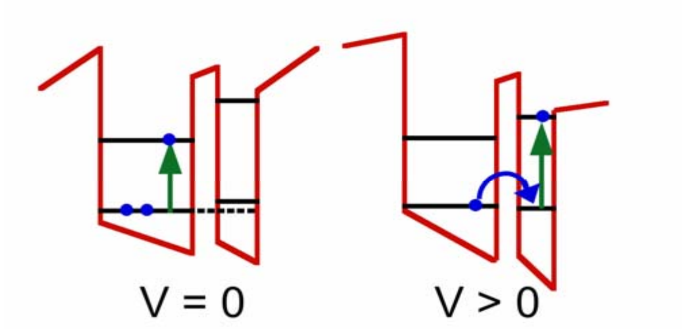

Fast quantum well photodetector (QWIPs)

*Giorgetta et al., Elec. Lett., **43**, 3 (2007)*



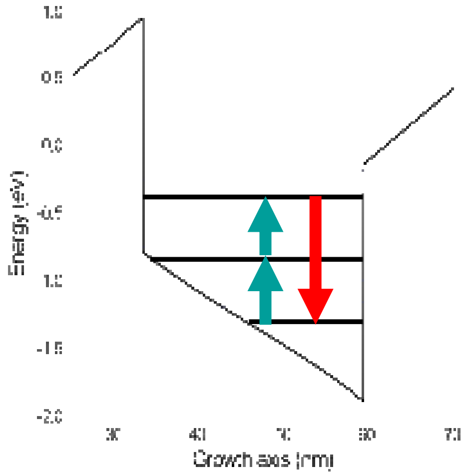

Multi-GHz electro-optical modulators based on coupled quantum wells

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

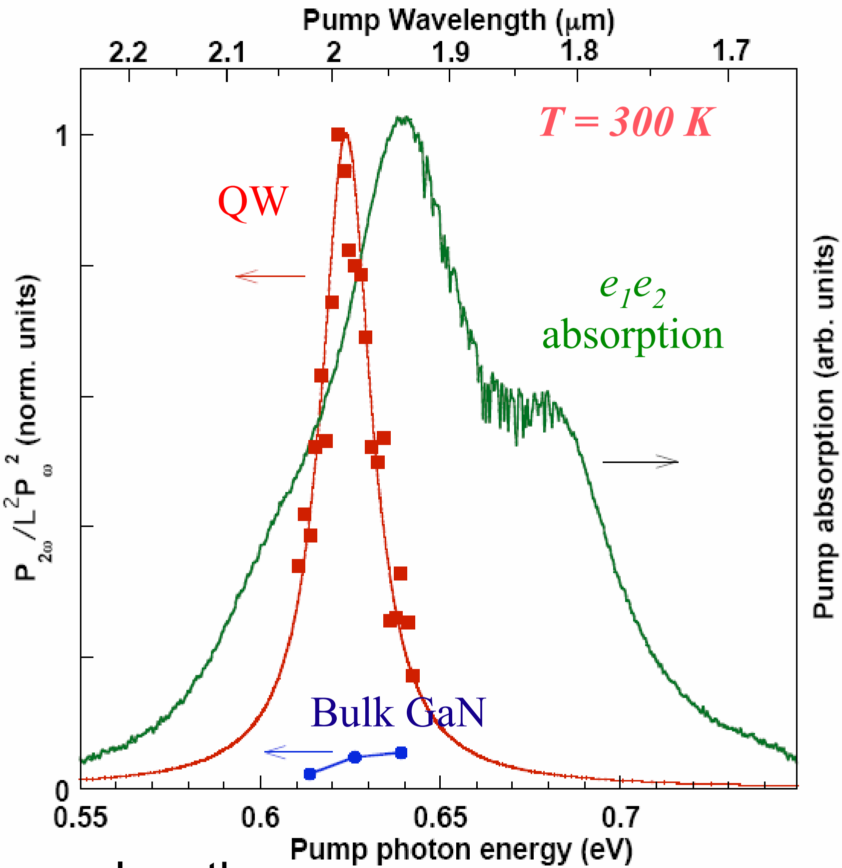



No emitting devices have been demonstrated up to recently!

# Emission at 1μm through resonant second-harmonic generation



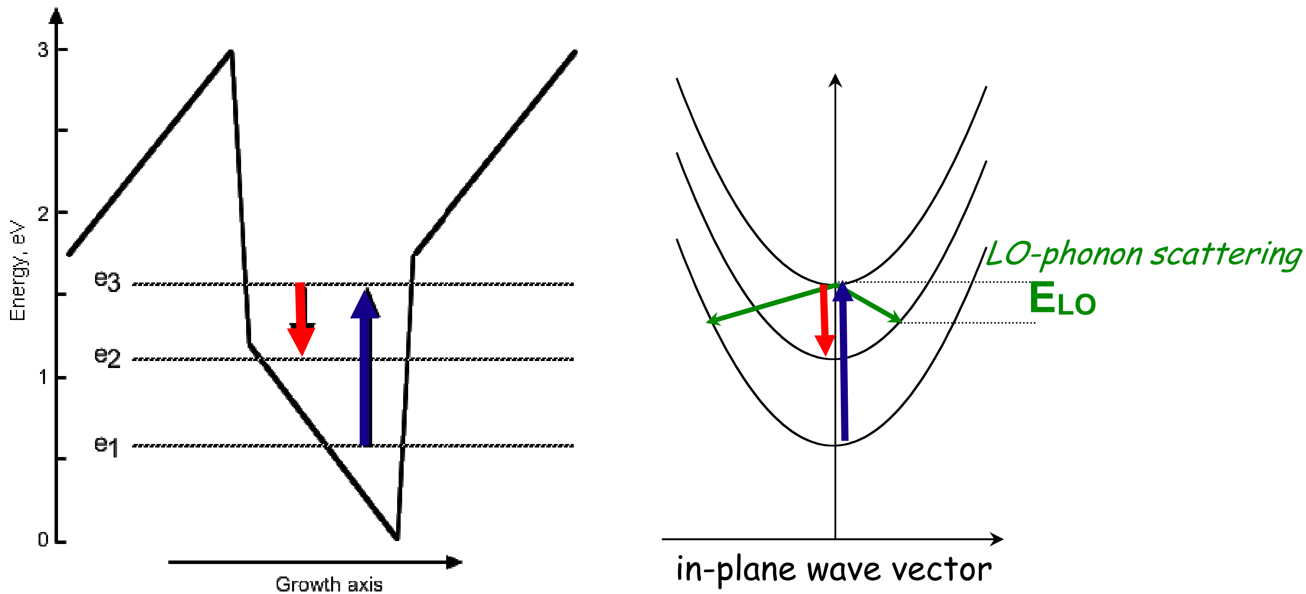

200 GaN/AlN QWs
2.6 nm well thickness




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

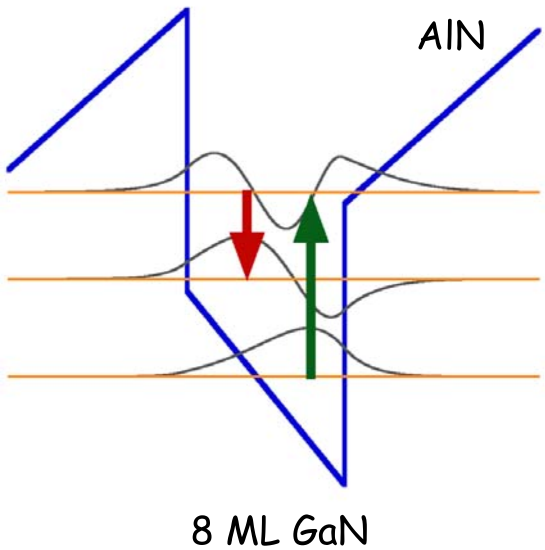
*Nevou et al., Appl. Phys. Lett.* ***89****, 151101 (2006).*

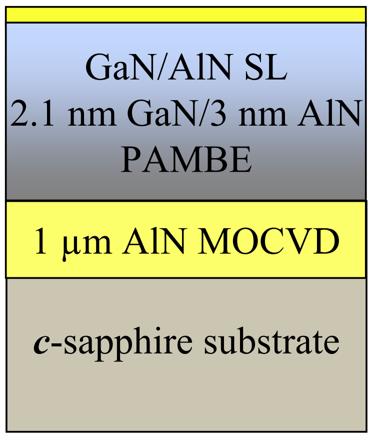
# Intersubband luminescence




- 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



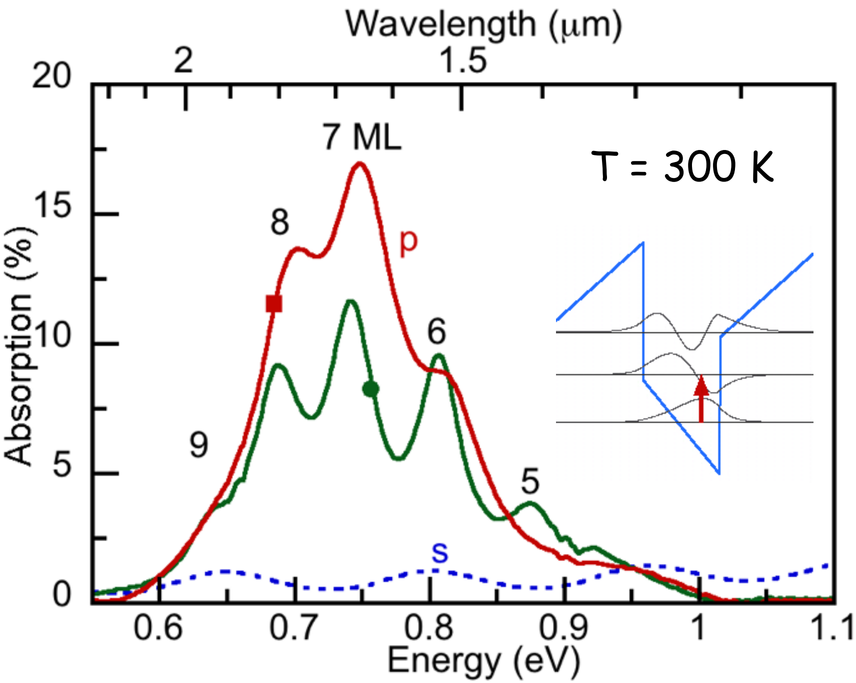

| E900 | E1000 |
|---|---|
| 250 periods | 200 periods |
| no Si doping | Si doping $5\times10^{19}\ cm^{-3}$ |

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

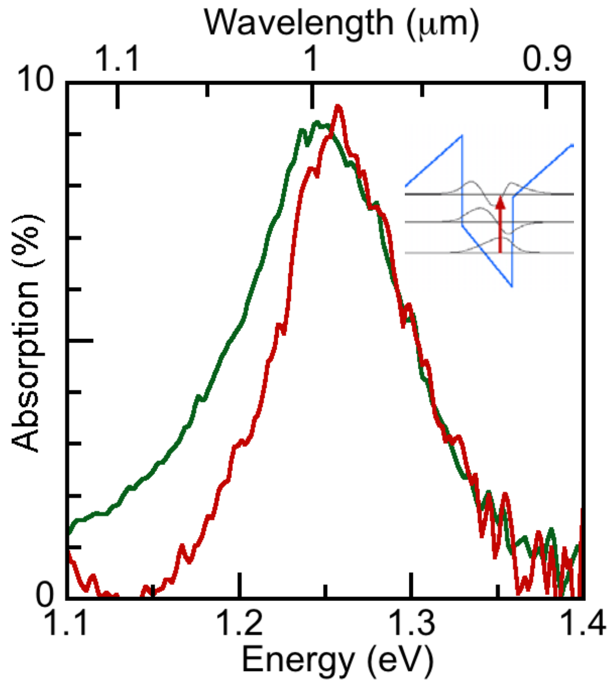
*L. Nevou et al., Electron. Lett.* ***42****, 1308 (2006); APL* ***90****, 121106 (2007)*

# ISB spectroscopy

| E900 | E1000 |
|---|---|
| 250 periods | 200 periods |
| no Si doping | Si doping $5 \times 10^{19}$ $cm^{-3}$ |



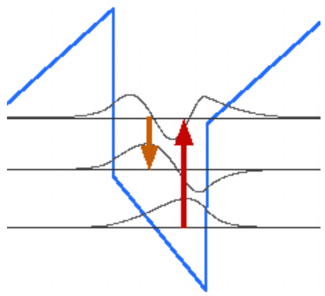

$e_1$-$e_2$ absorption (Brewster's angle)

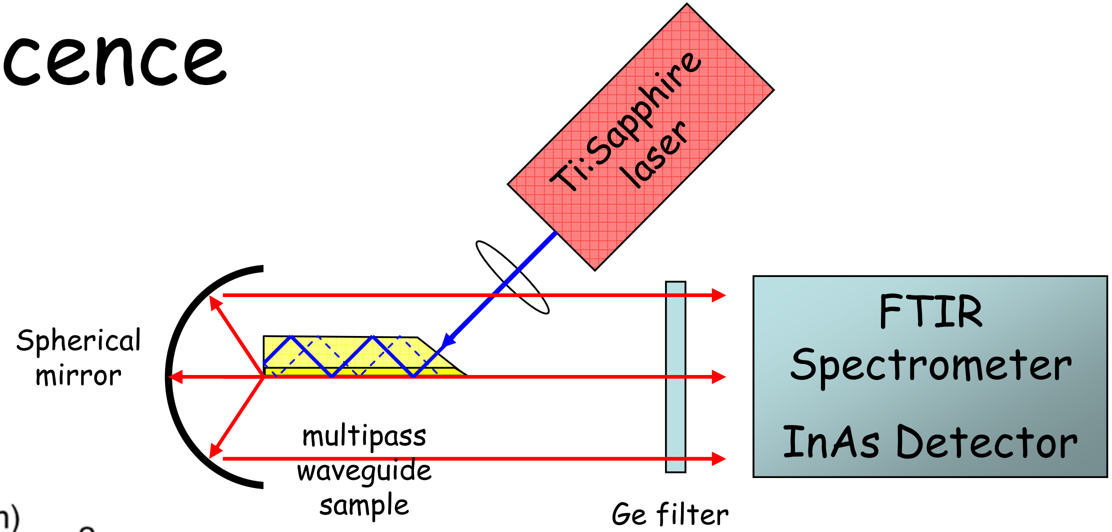


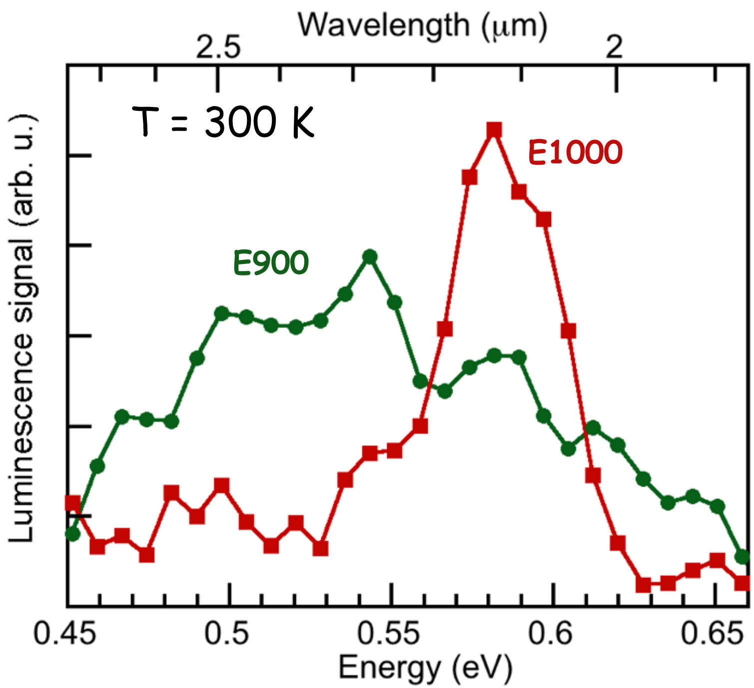

$e_1$-$e_3$ absorption (multipass waveguide)

*L. Nevou et al., Electron. Lett.* ***42****, 1308 (2006); APL* ***90****, 121106 (2007)*

# ISB luminescence



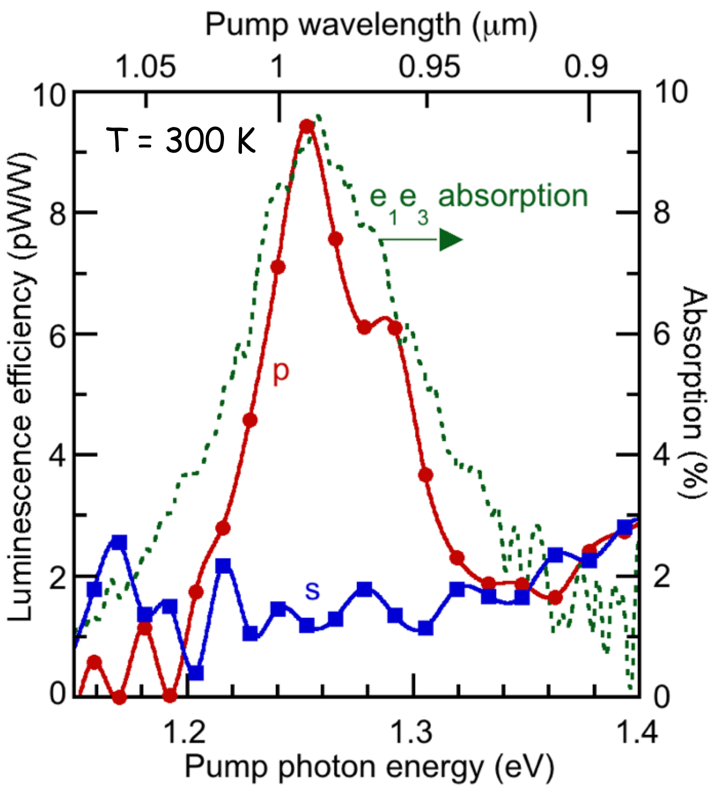



- p-polarized excitation @ 0.98 μm in resonance with $e_1e_3$ ISB absorption
- Emission strongly p-polarized
- Record short emission wavelength 2.13 μm
- 300 K !

*L. Nevou et al., Electron. Lett.* ***42****, 1308 (2006); APL* ***90****, 121106 (2007)*

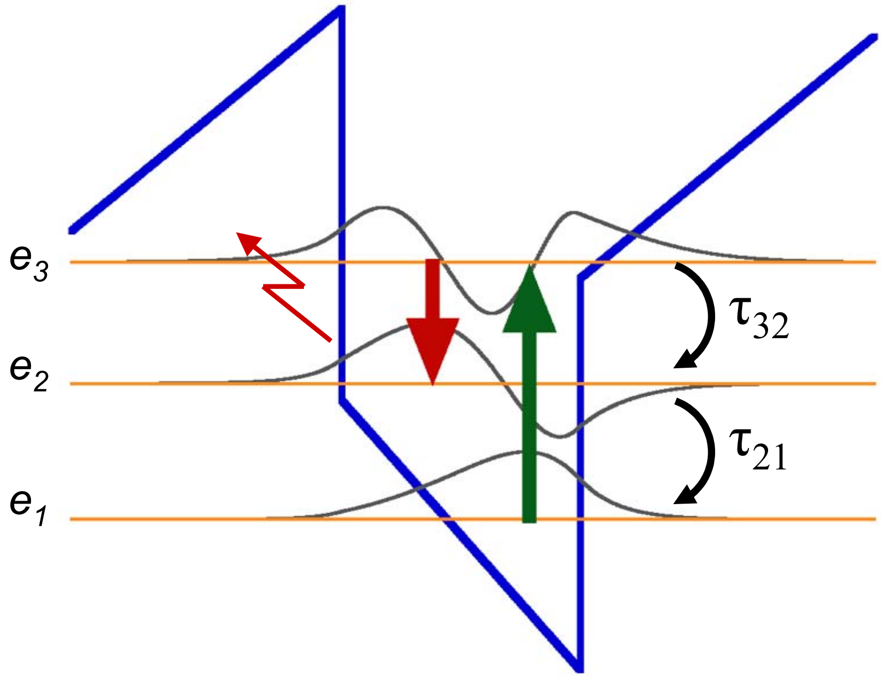
# ISB luminescence excitation spectroscopy




- 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 μW/Watt of pump power

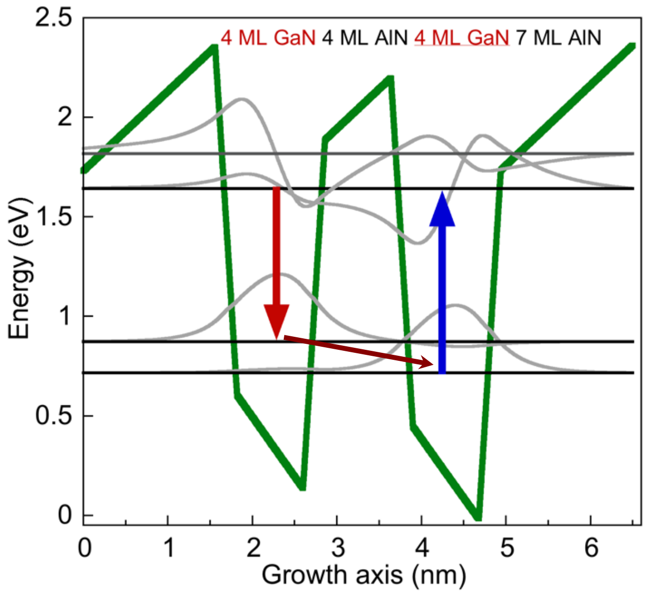
*L. Nevou et al., APL **90**, 121106 (2007)*

# Is population inversion achievable?



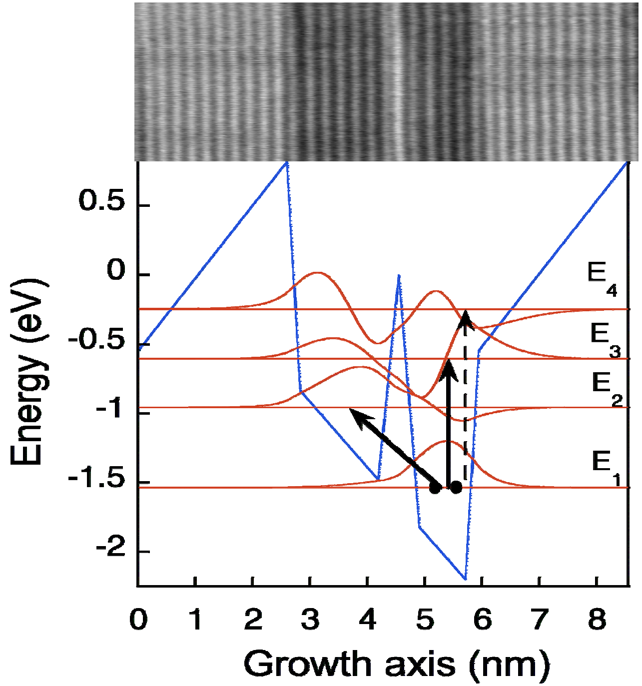

Condition for population inversion : $\tau_{21} < \tau_{32}$

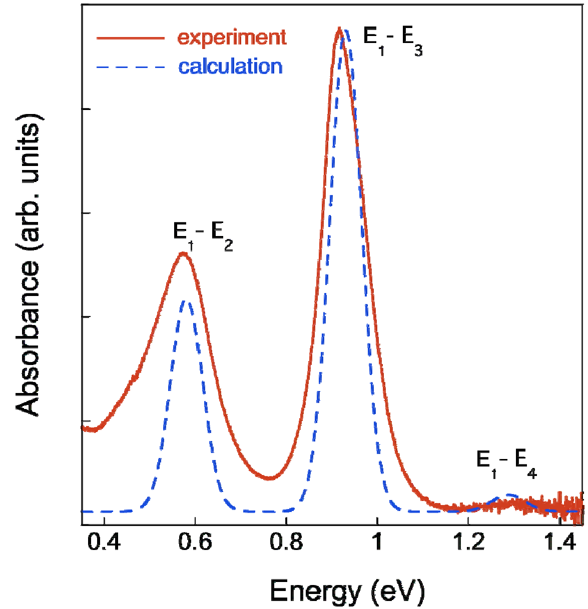
# Towards 1.5 μm ISB lasers




- 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

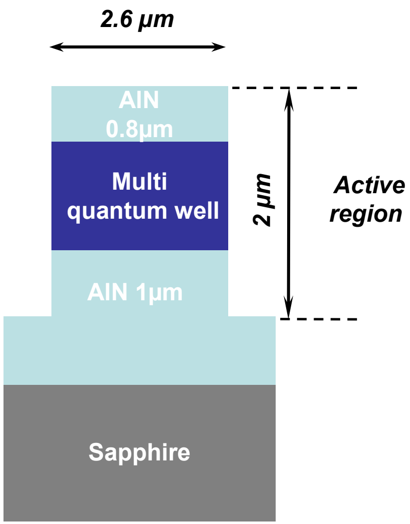


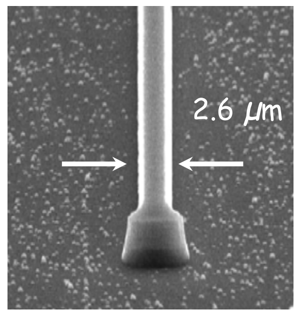




- Observation of $e_1e_2$ absorption is a signature of strongly coupled wells.
- The coupling vanishes for >4 ML thick AlN barriers.
- Excellent agreement with simulations assuming a potential drop at the interfaces spread over 1 ML

*M. Tchernycheva et al., APL **88**, 153113 (2006)*

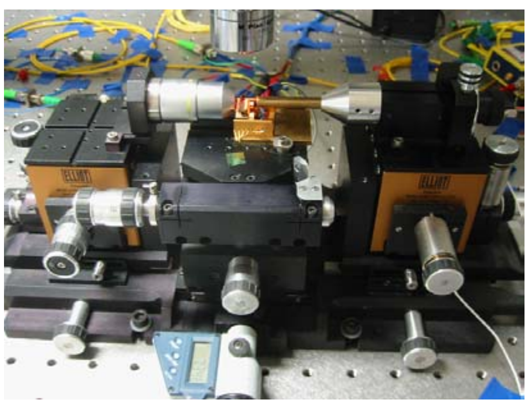
# Loss measurements on nitride waveguides

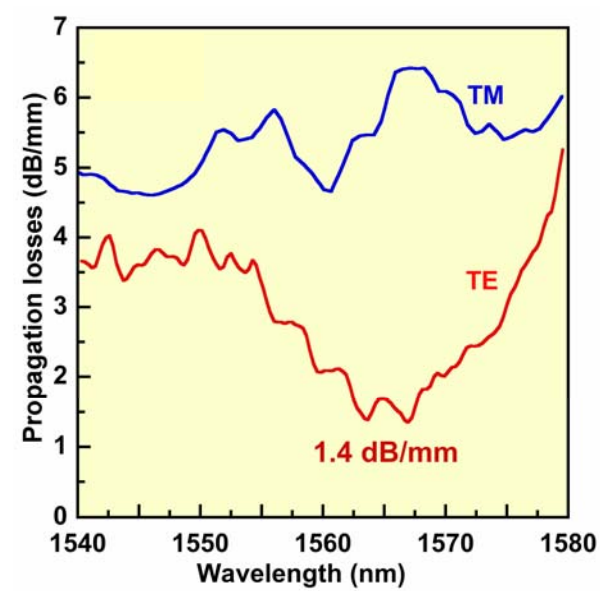



- Loss measurements on nitride waveguides @ 1.5 µm : 4 $cm^{-1}$ for TM polarization << estimated gain

A. Lupu et al.
(to appear in IEEE Phot. Techn. Lett. 2007)





# 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 $cm^{-1}$

*This work was supported by European FP6 NitWave program (contract IST #04170)*

NitWave