UNITRIDE

Unipolar Nitride Photonic devices

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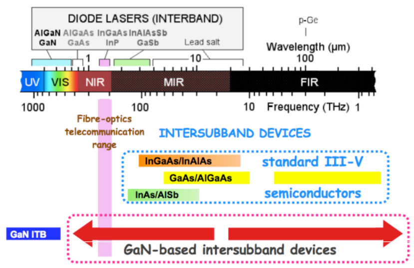
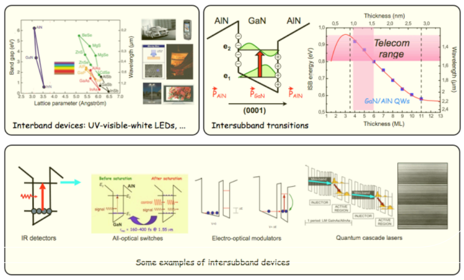
MOTIVATIONS

- Semiconductor materials can be made optically active at wavelengths regardless of their band gap by engineering the electron quantum confinement in ultrathin quantum well layers.
- A new class of optoelectronic devices can be realized with superior performances in terms of wavelength tuning, speed or optical power.
- These control-by-design devices rely on optical intersubband transitions between the electron confined states and the desired wavelength of operation can be obtained through a proper choice of the layer thicknesses.
- There is considerable interest in extending the wavelength range of intersubband devices from the near- to the far-infrared spectrum.
- As examples, high-power lasers, sensitive room-temperature detectors or ultrafast optical processing devices are highly demanded.
- Numerous appealing applications: telecommunication optoelectronic devices at optical-fiber transmission windows, chemical sensing and pollution detection, industrial process monitoring, night vision, non-invasive medical diagnostics, automotive anti-collision monitoring systems, lidars...

Why GaN-based quantum engineered devices

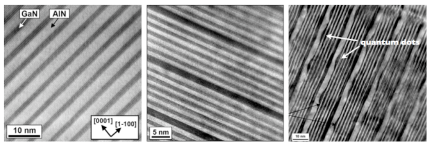


Towards III-nitride photonics from UV to THz



State-of-the-art material growth

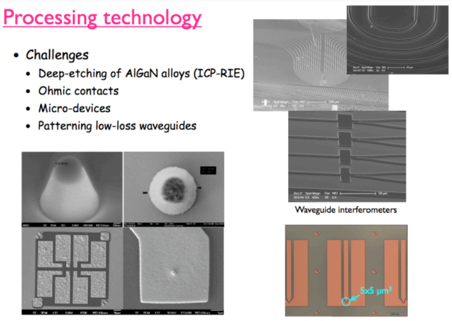
- Challenges:
  - thickness control of ultra thin layers down to one atomic monolayer.
  - high quality layers and interfaces, strain management.
- Molecular beam epitaxy using nitrogen plasma or ammonia cracking.



Transmission electron microscopic images of GaN/AlGaN quantum well and quantum dot superlattices

Processing technology

- Challenges
  - Deep-etching of AlGaN alloys (ICP-RIE)
  - Ohmic contacts
  - Micro-devices
  - Patterning low-loss waveguides



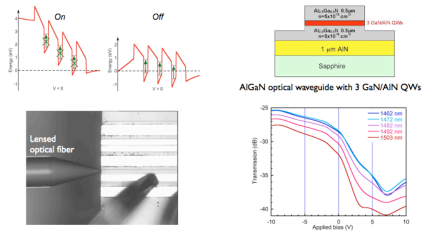
Waveguide interferometers

Nano-diodes with 300 nm diameter

High-speed quantum cascade detectors

Electro-optical modulators

- Amplitude modulators at 1.3-1.55 μm wavelength



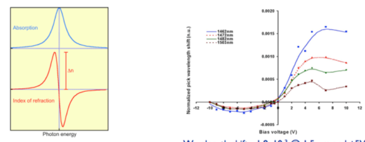
AlGaN optical waveguide with 3 GaN/AlN QWs

Top view of the device

Amplitude modulation >13 dB

H. Machhadani, P.K. Kandaswamy, S. Sakr, A. Vardi, A. Wirtmüller, L. Nevou, F. Guillot, G. Pozzovivo, M. Tchernycheva, A. Lupu, L. Vivien, P. Crozat, E. Warde, C. Bougerol, S. Schacham, G. Strasser, G. Bahir, E. Monroy, and F. H. Julien, "GaN/AlGaN intersubband optoelectronic devices", New Journal of Physics 11, 125023 (2009)

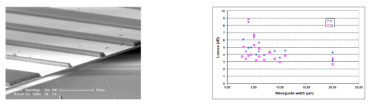
- Demonstration of the first intersubband phase modulator



Wavelength shift ~1.8x10⁻³ @ 1.5 μm and ±5V

First demonstration of ISB index modulation: Δn/n ~4x10⁻³ (10 times larger than in silicon).

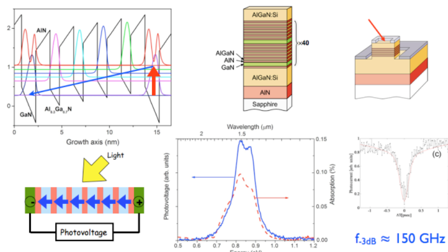
- Optical waveguides with record low propagation losses



GaN waveguides fabricated by ICP-RIE deep etching. The waveguide losses are < 10 dB/cm.

Quantum cascade detectors

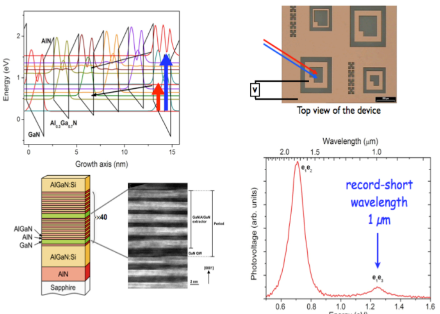
- Ultra-high speed detectors at 1.3-1.55 μm wavelength



$f_{3dB} \approx$ 150 GHz

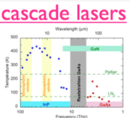
S. Sakr, S. Haddadi, M. Tchernycheva, L. Vivien, I. Sarigiannidou, N. Isac, E. Monroy, F. H. Julien, "GaN-based quantum cascade photodetectors with 1.5 μm peak detection wavelength", Electron. Lett. 46, 1685 (2010)

- The first two-color quantum cascade detector



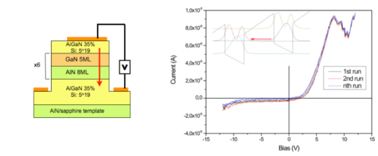
Towards GaN-based quantum cascade lasers

- Challenges:
  - Injection of electrons via resonant tunneling
  - Tuning ISB transitions at long wavelengths



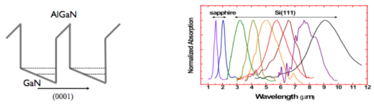
Maximum operating temperature of quantum cascade lasers

- Observation of resonant tunneling:



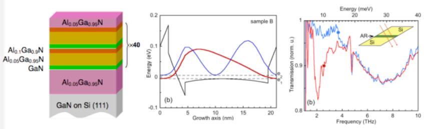
First observation of reproducible quantum cascade resonant tunneling ($e_1 \rightarrow e_2$) in a GaN/AlGaN device.

- Tuning ISB absorption up the Reststrahlen band of GaN



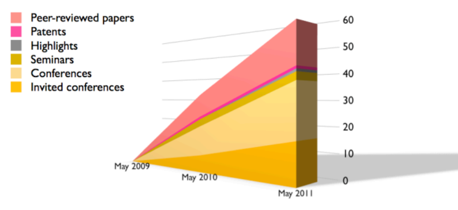
P. K. Kandaswamy, H. Machhadani, C. Bougerol, S. Sakr, M. Tchernycheva, F. H. Julien, and E. Monroy, "Midinfrared intersubband absorption in GaN/AlGaN superlattices on Si(111) templates", Appl. Phys. Lett. 95, 141911 (2009)

- First demonstration of ISB absorptions at THz frequencies



H. Machhadani, Y. Kotsar, S. Sakr, M. Tchernycheva, R. Colombelli, J. Mangeney, E. Bellet-Amalric, E. Sarigiannidou, E. Monroy, F. H. Julien, "Terahertz intersubband absorption in GaN/AlGaN step quantum wells", Appl. Phys. Lett. 97, 191101 (2010)

Dissemination:



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