50 years of the Institute of High Pressure Physics Polish Academy of Sciences
Highlights in III-V semiconductors, THz physics and nanomaterials
Anniversary Symposium „Unipress 50”

New device concepts enabled by tunnel junction

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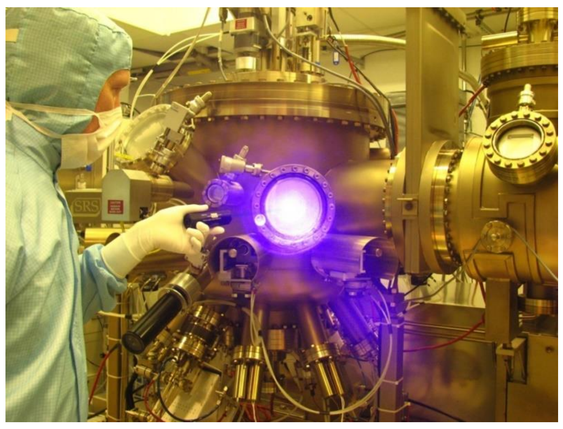
Plasma-assisted molecular beam epitaxy (PAMBE)

PAMBE advantages:
- Low temperature high quality nitride layers growth
- High doping levels possible
- No need to activate p-type doping

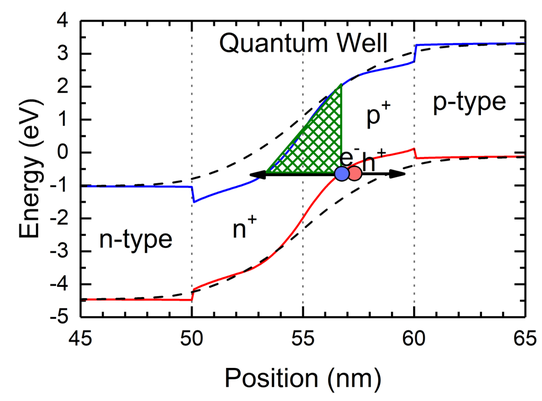
First laser diode (LD) by PAMBE 2004

Long living (100 000 h) true blue LDs



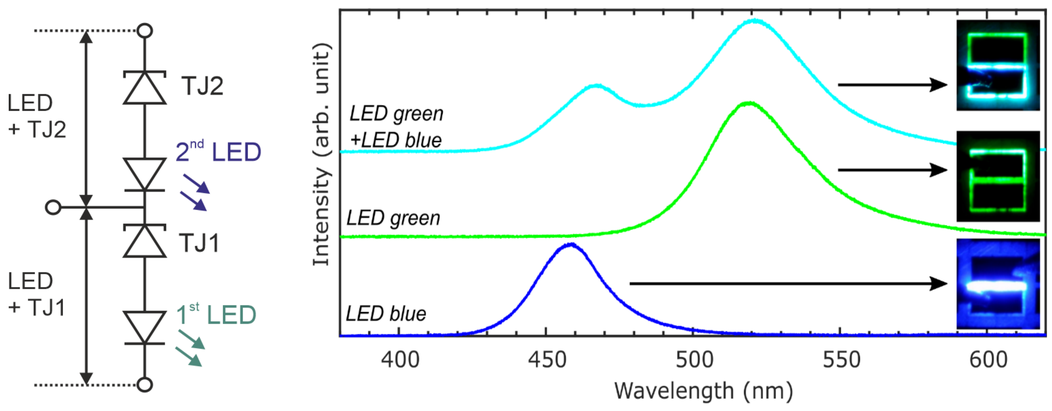
Tunnel junction (TJ)

Tunnel junction enables the generation of electrons in n-type and holes in p-type through tunneling process [1].
The 3.4 eV bandgap of GaN causes high barrier for tunneling. In order to obtain high tunneling currents we use heavy doping inside InGaN QW, which reduces the depletion width and barrier height [2].

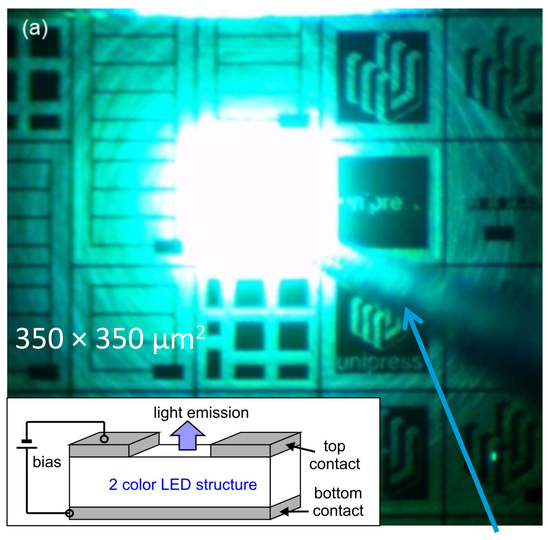


Vertically integrated LEDs

The stack of blue-green light-emitting diodes (LEDs) was processed in a way to obtain either emission from a single LED or from both LEDs.

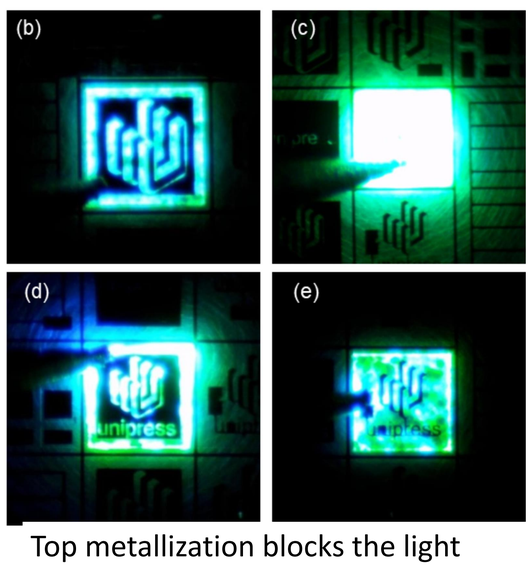


Operating multicolor TJ LED, surrounded by other devices.



LED chip is biased though a needle placed on top and bright light emission is visible.

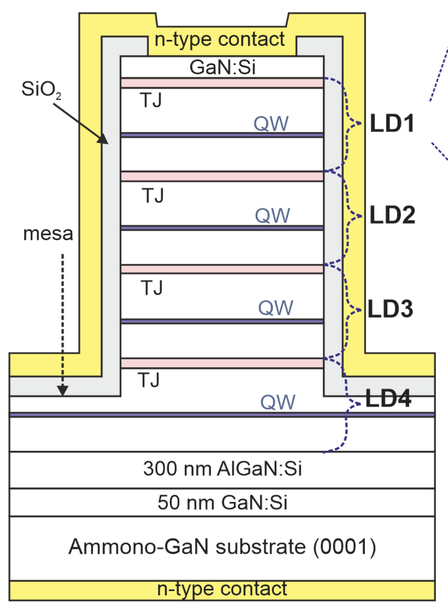
Operation of LEDs with different metallization patterns

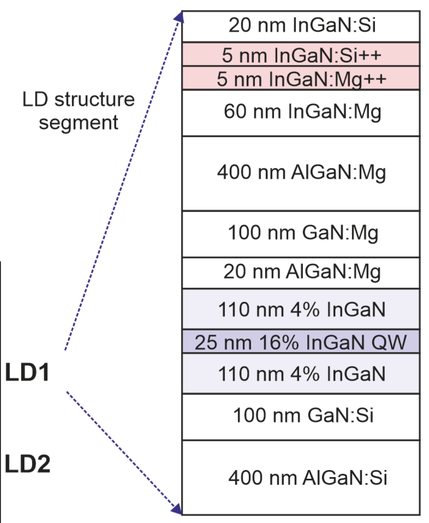


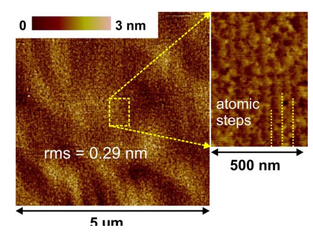
Top metallization blocks the light generated in the active region and top contact pads are visible as black

Vertically integrated LDs

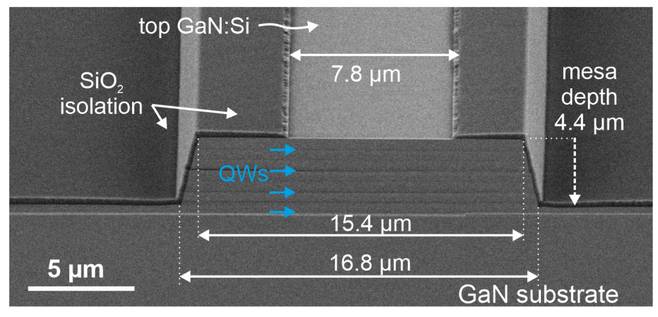
Four LDs were interconnected by TJs and processed as a single device [3].



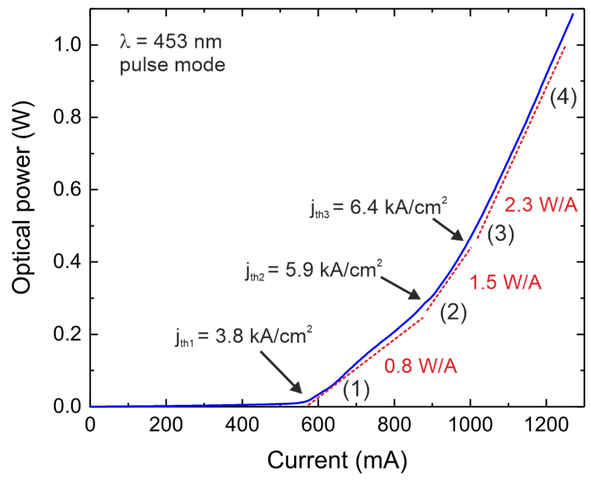


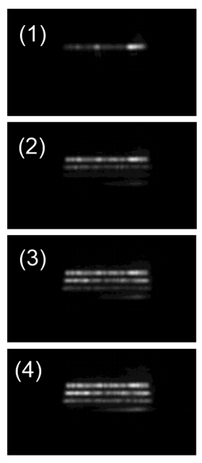


Surface morphology after 4-LDs stack growth is atomically smooth.



The light–current characteristics of the stack of four LDs structure grown by PAMBE. Three lasing thresholds are observed. Total slope efficiency follows the number of lasing devices multiplied by slope efficiency of the first LD.





The near-field patterns collected by Gaussian beam telescope setup for the lasing regions (1)–(4) denoted in the light–current characteristics

References

1. L. Esaki, "New Phenomenon in Narrow Germanium p-n Junctions," Physical Review 109, 603 (1958).
2. M. Żak et al., "Tunnel Junctions with a Doped (In,Ga)N Quantum Well for Vertical Integration of III-Nitride Optoelectronic Devices," Physical Review Applied 15, 024046-1 (2021).
3. M. Siekacz et al., "Vertical Integration of Nitride Laser Diodes and Light Emitting Diodes by Tunnel Junctions," Electronics 9 (2020).
4. G. Muziol et al., "Distributed-feedback blue laser diode utilizing a tunnel junction grown by plasma-assisted molecular beam epitaxy," Opt. Express 28, 35321 (2020).

Summary

- TJ allowes for high output power of LDs and fabrication of multicolor laser stacks.
- Implementaiton of TJ in nitride device structures allows for other novel device constructions (not shown here) such as:
  - distributed-feedback laser diodes (DFB LDs) with diffraction grating located directly on top of the ridge [4],
  - wavelength tunable LEDs emitting from 480 to 640 nm,
  - LEDs for cryogenic temepratures, AC-driven LEDs,
  - and many more.

The poster is also avaialable on-line