SAND2020-0836C

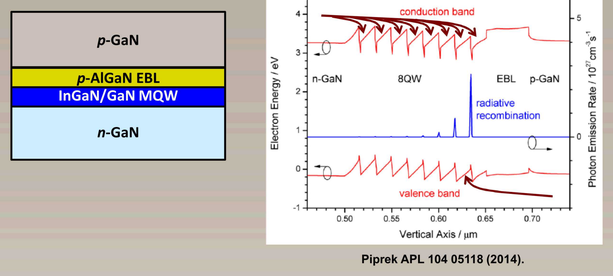
Tunneling-Enabled High-Efficiency High-Power Multi Junction LEDs

Andrew Armstrong,[1] Najib Hasan,[2] Zane Jamal-Eddine,[2] Brendan Gunning,[1] Mary Crawford,[1] Jinwoo Kim,[2] Shamsul Arafin,[2] and Siddharth Rajan[2]

[1]Sandia National Laboratories, [2]Ohio State University

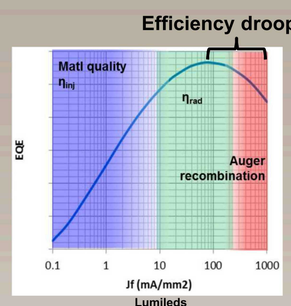
LEDs suffer efficiency droop at high current density

Standard "1x8" LED



Piprek APL 104 05118 (2014).

Current droop

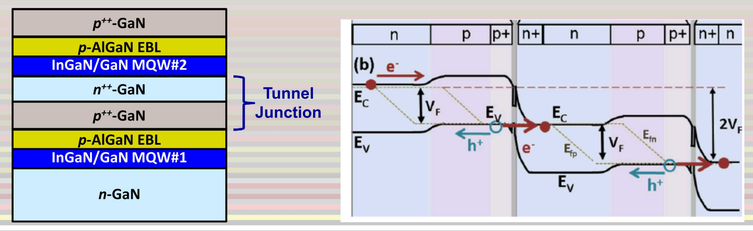


Auger recombination causes current droop in InGaN LEDs

- Hole "pile up" at p-side QW causes high carrier density and Auger recombination
- Improve hole distribution to mitigate current droop

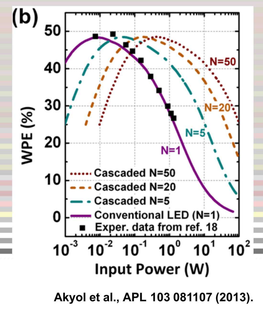
Mitigate current droop using multi-junction LEDs

TJ-enabled MJ-LED



Akyol et al., APL 103 081107 (2013).

Reduced current droop



Akyol et al., APL 103 081107 (2013).

Stacking MQWs reduces current density needed for high output power

- Tunnel junctions (TJs) act as a distributed hole injector
- Mitigates current droop by improving light output at same current density

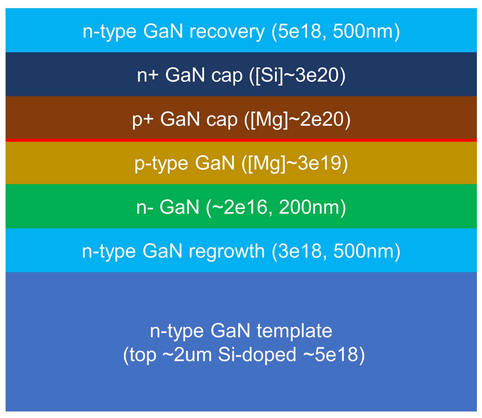
Technical approach

All-MOCVD MJ-LED

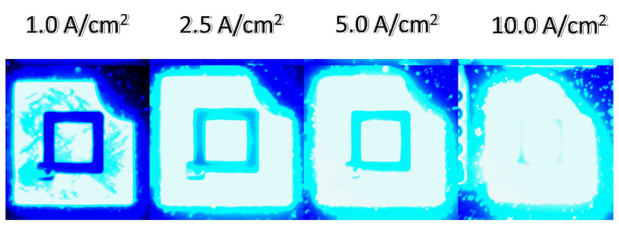
- All-MOCVD solution is optimum techno-economic solution
- Enables rapid adoption by LED industry
- High reward but also high risk due to immature MOCVD TJ technology

Successful activation of buried p-GaN:Mg layers

TJ device structure



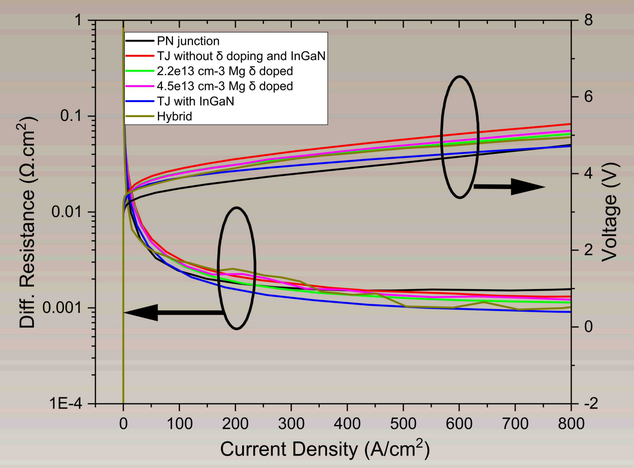
Electroluminescence of TJ device



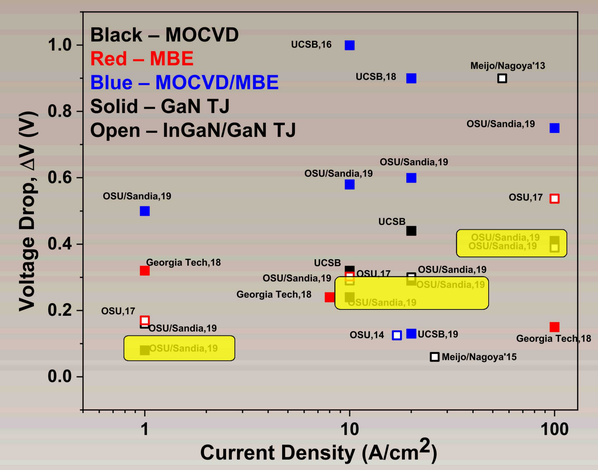
- Standard rapid thermal anneal conditions (900℃, 30 min) activates buried p-GaN
- Lateral H diffusion to sidewall effective for 105 μm mesas

Achieved low resistivity MOCVD TJs

MOCVD TJ *I-V* and differential resistivity



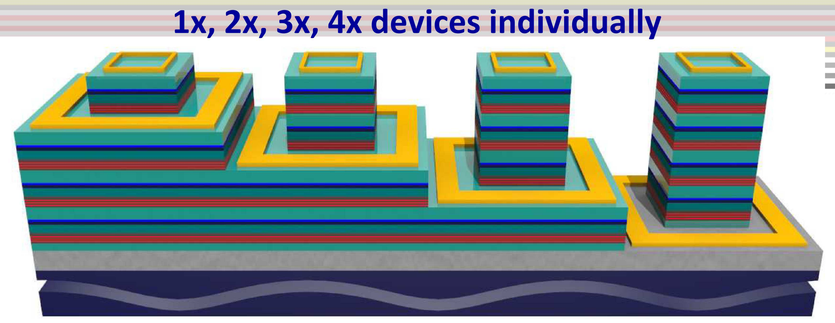
Comparison to previous results



- Various designs achieved $\rho < 2$ mΩ.cm^2 at low current density relevant to LEDs
- Voltage penalty of TJ relative to standard p-n junction among the lowest reported for all-MOCVD device

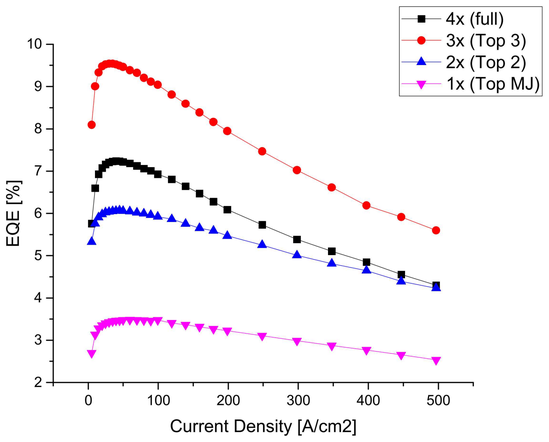
TJ-enabled multi-junction LEDs

Multi-junction LED processing to test 1x, 2x, 3x, 4x devices individually

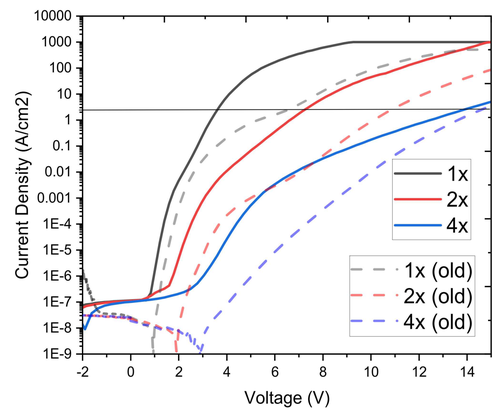


Device stack	Voltage drop at 2.5 A/cm2 (new condition)	Voltage drop at 2.5 A/cm2 (Old condition)
1x	3.6	6.6
2x	7.2	10.9
4x	13.9	14.6

On-wafer multi-junction EQE (old activation condition)



Improved multi-junction LED turn-on voltage with new activation condition



- Multi-junction LEDs show linear EQE scaling for up to 3x junctions
- Absolute EQE low due to on-wafer testing w/o light extraction techniques
- Greatly reduced turn-on voltage using new activation conditions

Summary and Next Steps

- **Achieved sufficiently low ρ TJs for a 3x MJ-LED**
- **All-MOCVD GaN ρ_{TJ} among lowest reported**
- **Demonstrated linear EQE and turn-on voltage scaling in multi-junction LEDs**

This work was supported by the Laboratory Directed Research and Development program at Sandia National Laboratories. Sandia National Laboratories is a multi-program laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC (NTESS), a wholly owned subsidiary of Honeywell Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.