InGaN–GaN Multiple Quantum Wells for Green LEDs on Si

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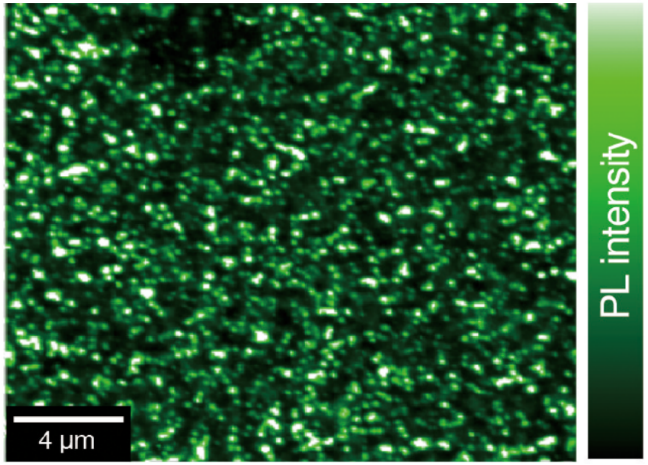
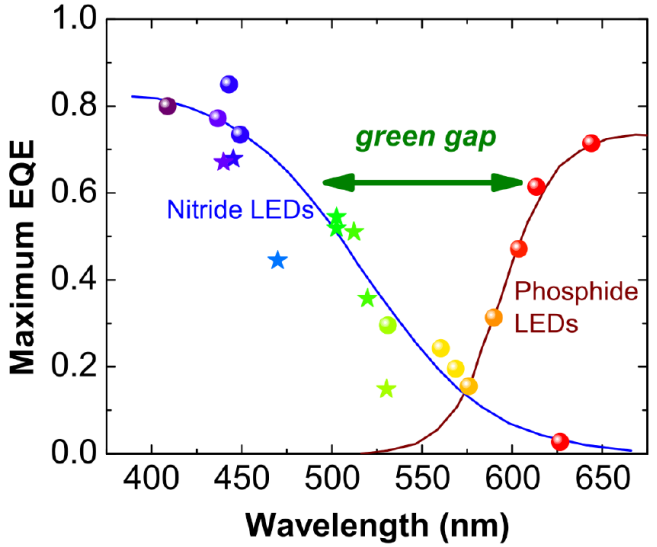
June 7th, 2018

Green InGaN–GaN Light Emitting Diodes

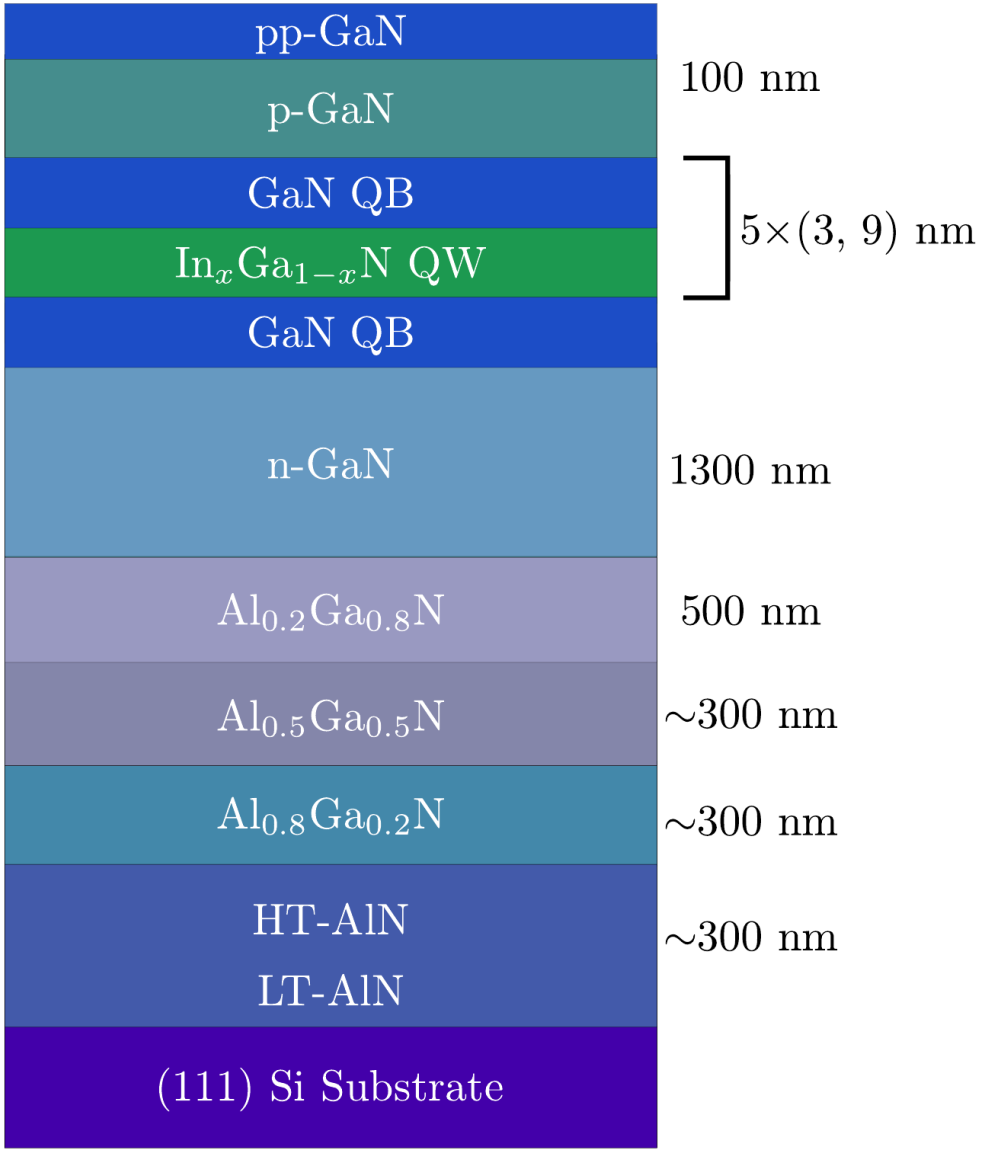




- III-N direct bandgaps cover UV to IR wavelengths
- $In_xGa_{1-x}N$ with $x \approx 20\%$ for direct green emission
- Complex alloy picture: growth and misfit defects, phase separation, spontaneous and piezoelectric polarization...

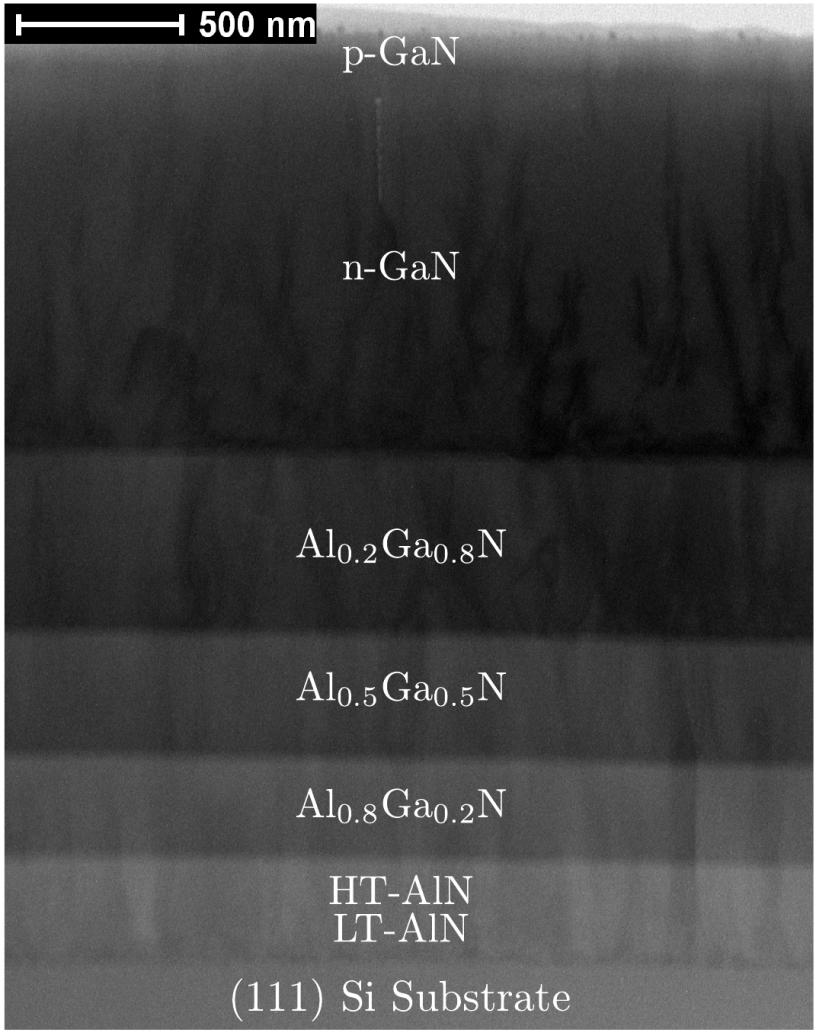
Left figure adapted from Jeong, H. et al. en *Scientific Reports* **Mar. 2015**, *5*, 9373. Right figure from Auf der Maur, M. et al. *Physical Review Letters* **Jan. 2016**, *116*, 027401.

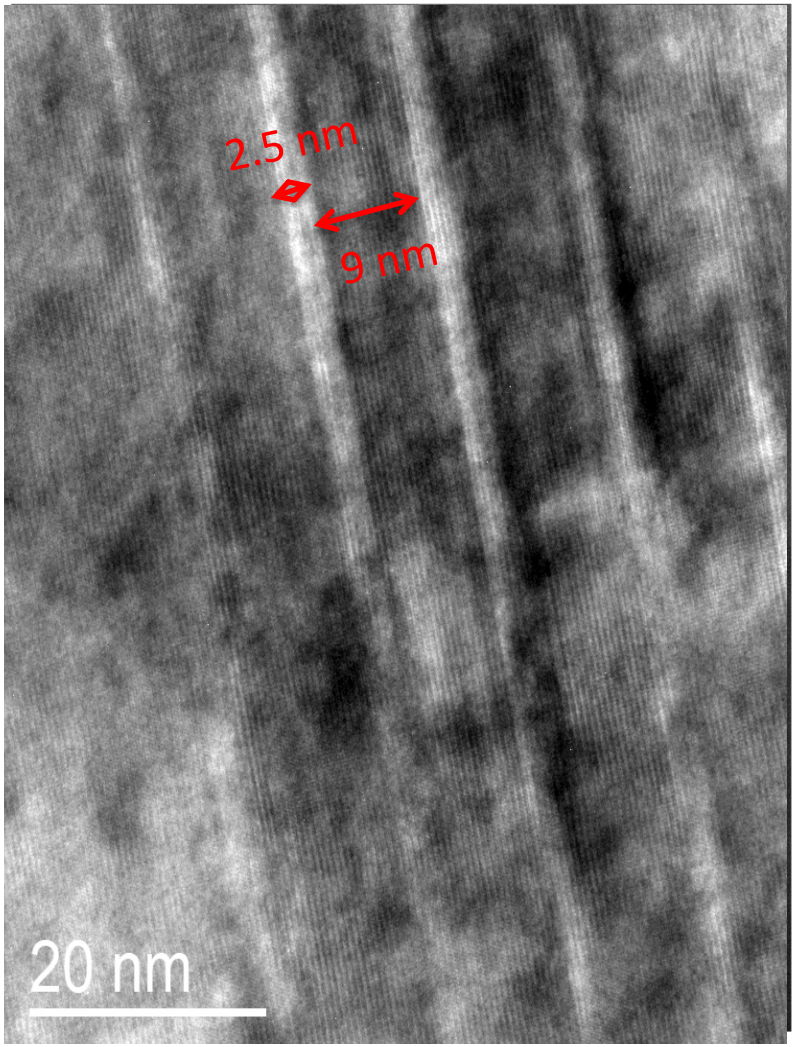
Green Multiple Quantum Well LED on Si



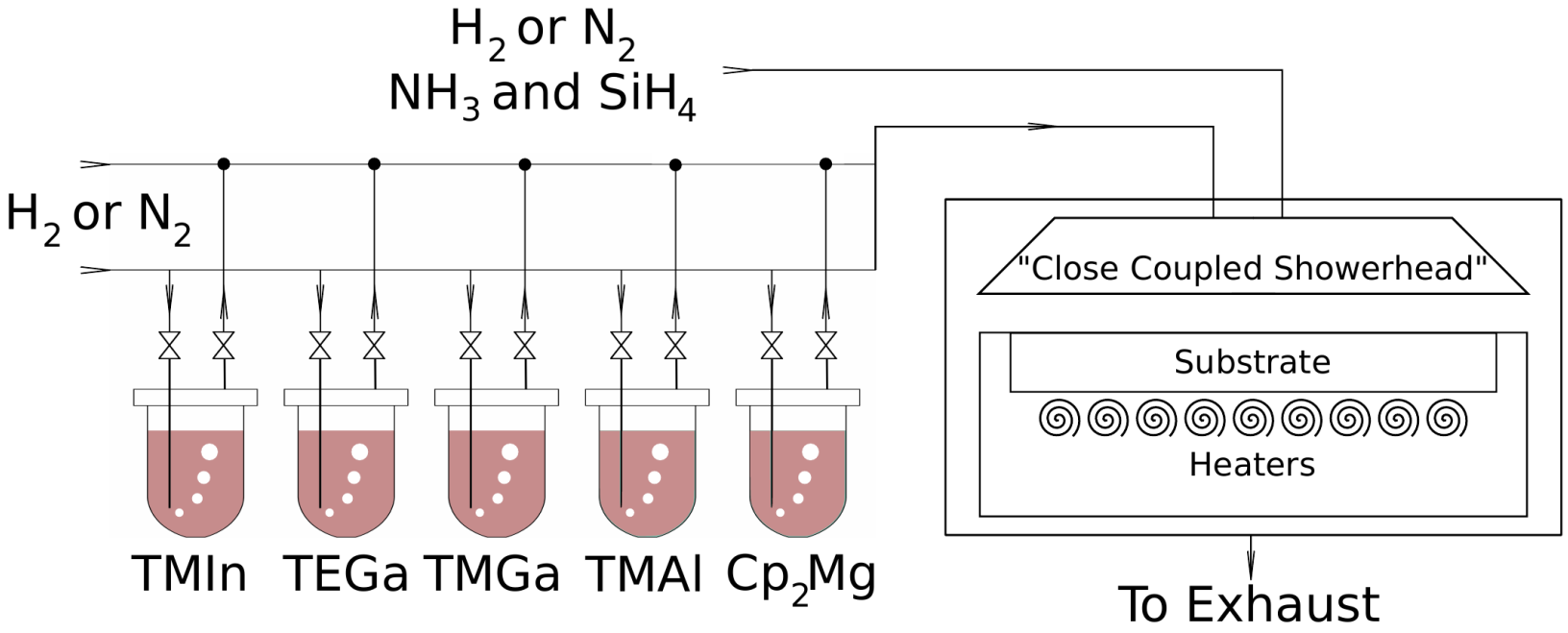
- GaN on Si: lattice mismatch, thermal mismatch, Ga etchback
- Pre-existing buffer structure for GaN on Si in SNF, adopted for GaN MQW LED on Si growth
- Not wafer scale without optimization, but 100 µm to 1000 µm between observed cracks.

General Result by Transmission Electron Microscopy



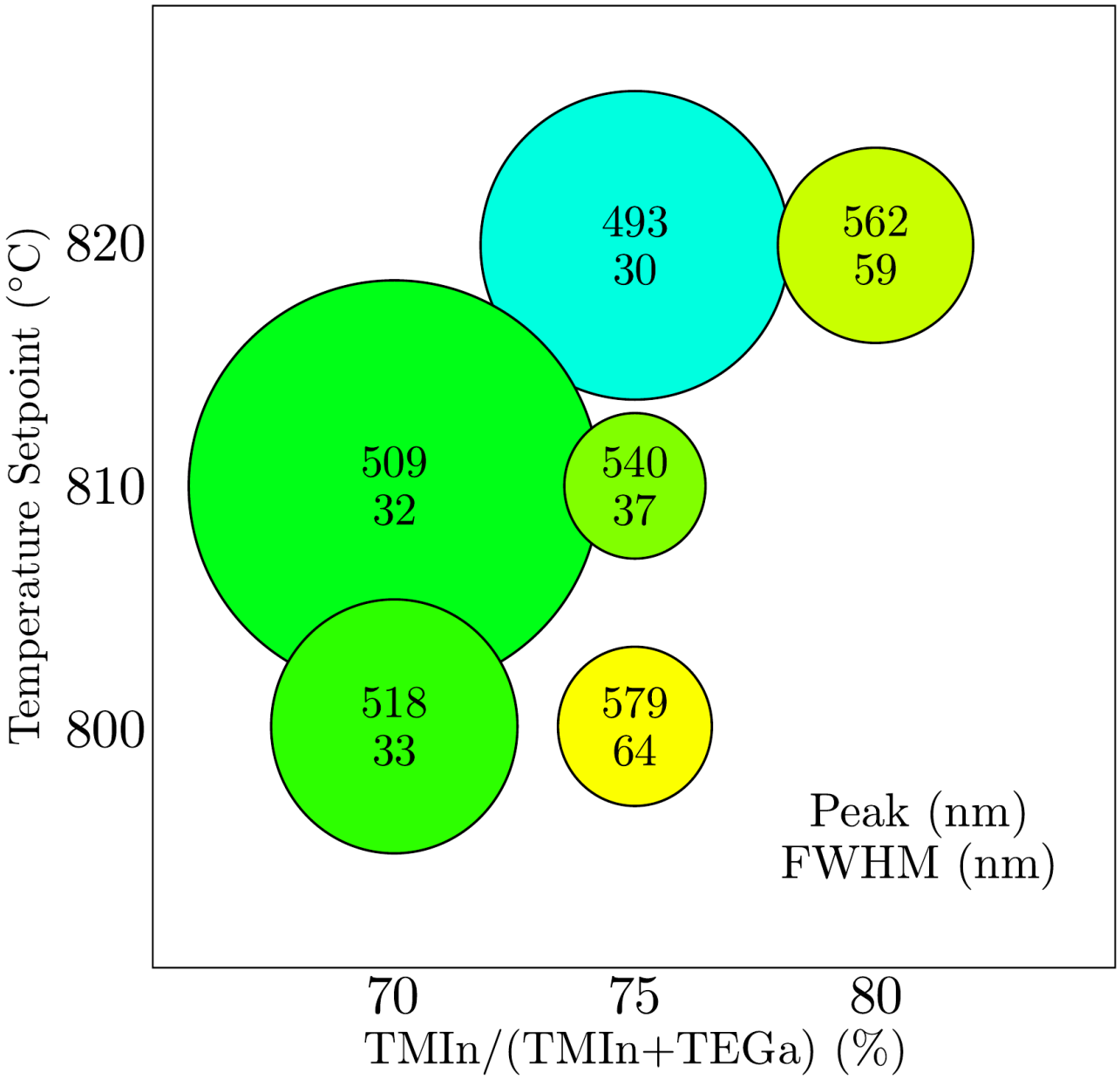


Organometallic Chemical Vapor Deposition (MOCVD)

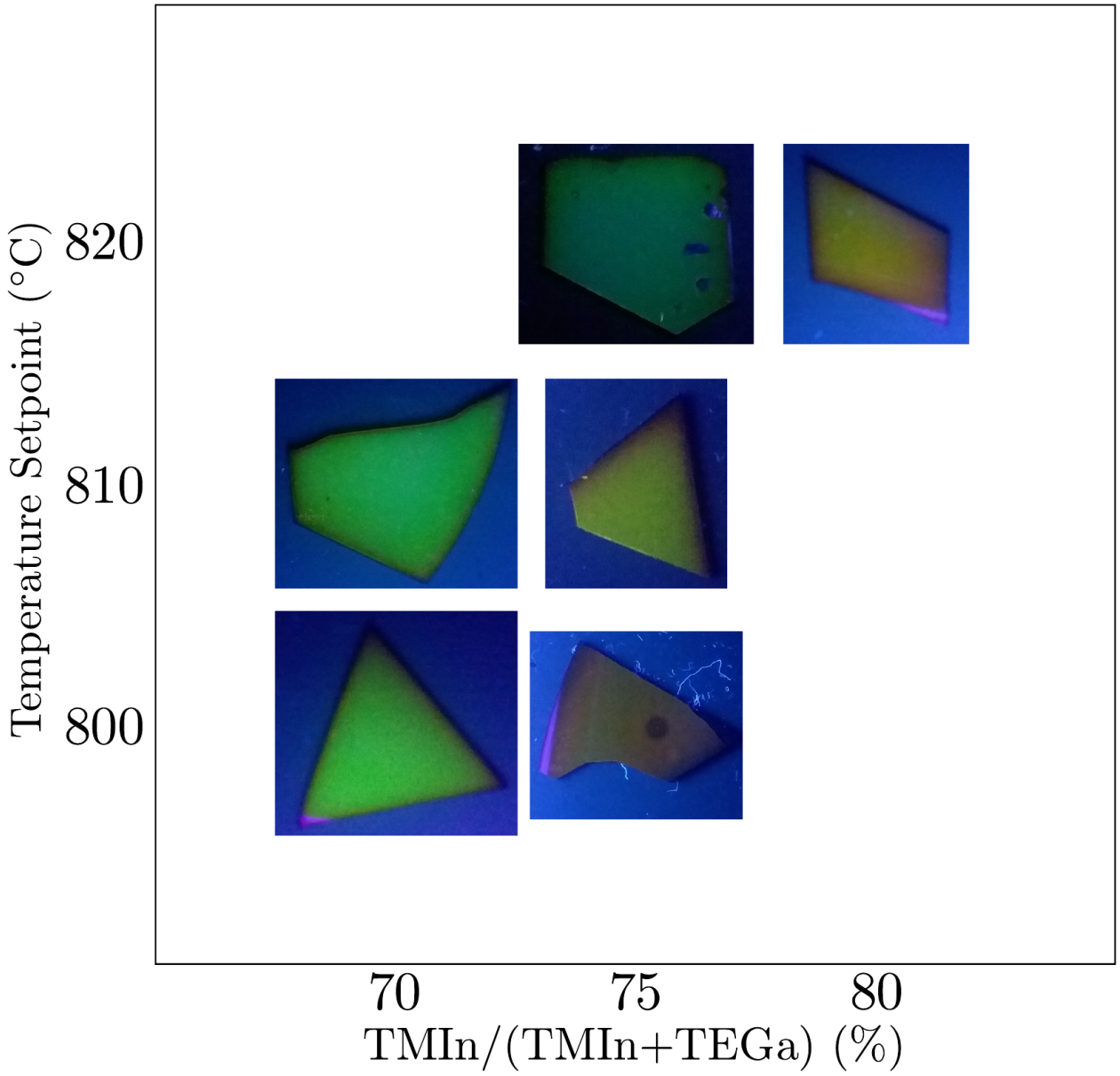


- Thin film deposition process for large-area, nm-scale, epitaxial thin films
- Precursors pyrolize on heated growth substrate at 700 °C to 1100 °C (for our experiments)
- Heavy use in industrial production of LEDs

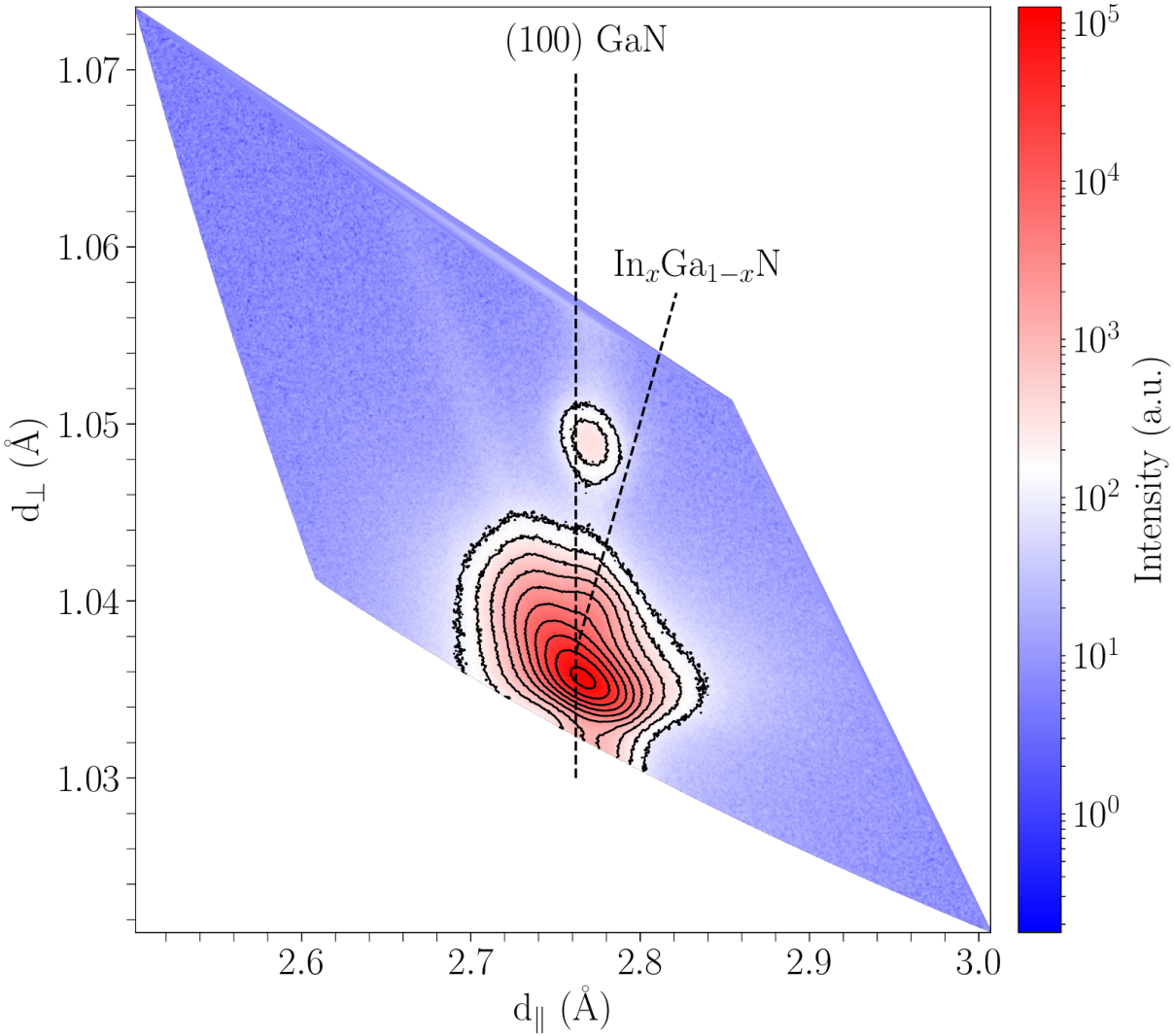
T–TMIn/III vs λ Space for MQW LED Structures



Specimen Photoluminescence at 365 nm

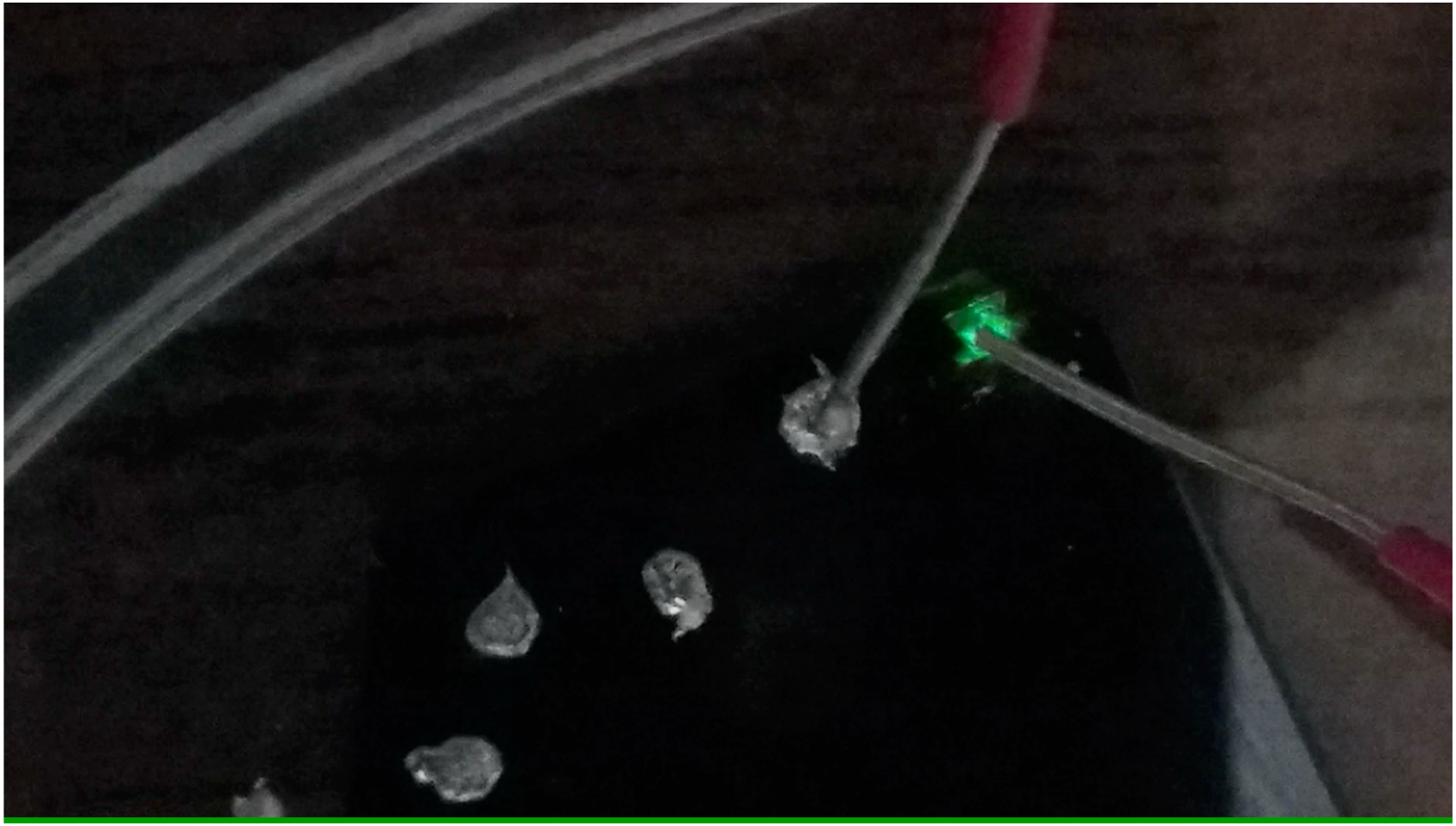


Incoherent Strain and X-ray Diffraction, $\bar{1}05$

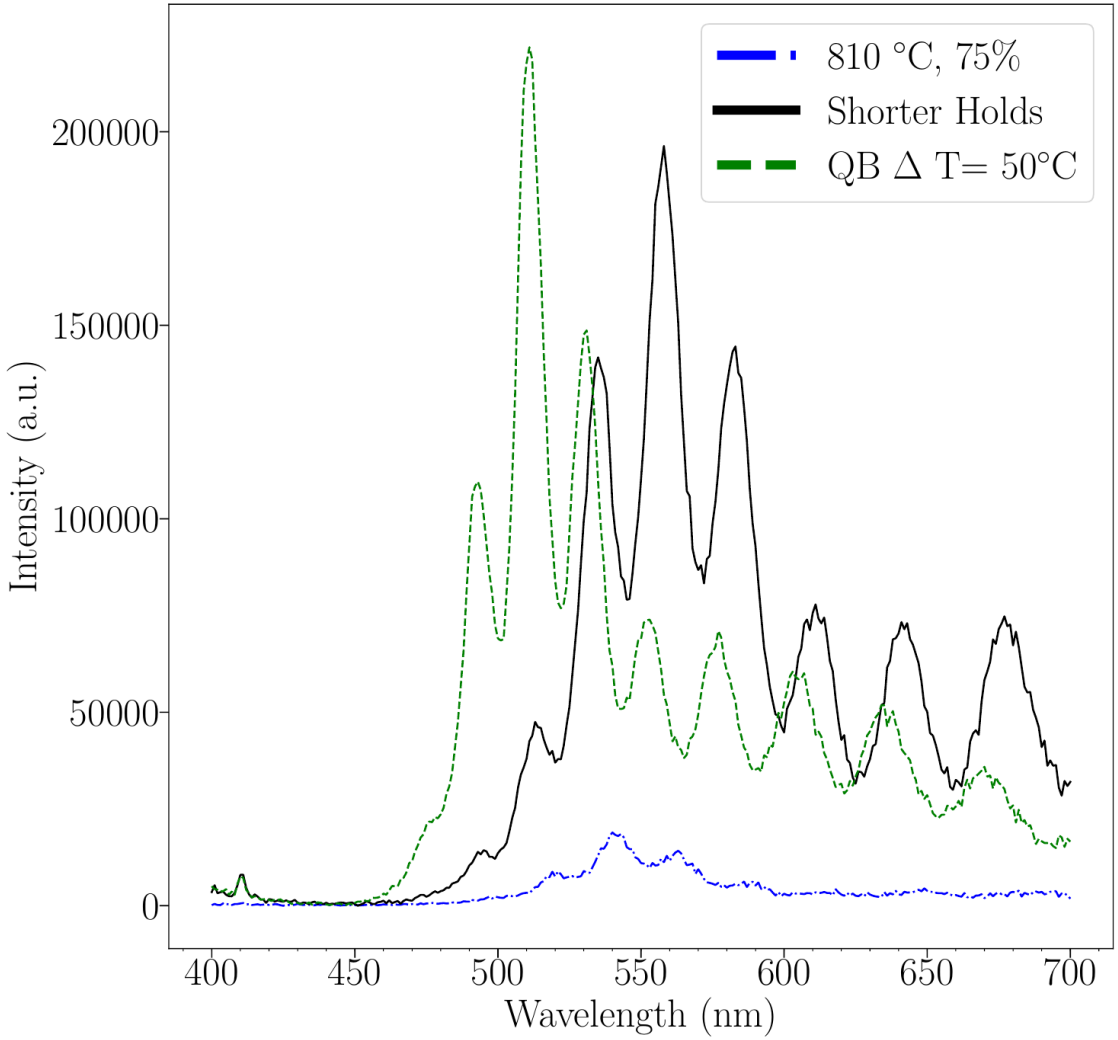


- 2/3 InGaN growth time + all measured specimens incoherent
- (002) maps prove GaN-InGaN in-plane lattice mismatch

Qualitative Electroluminescence



Additional Experiments

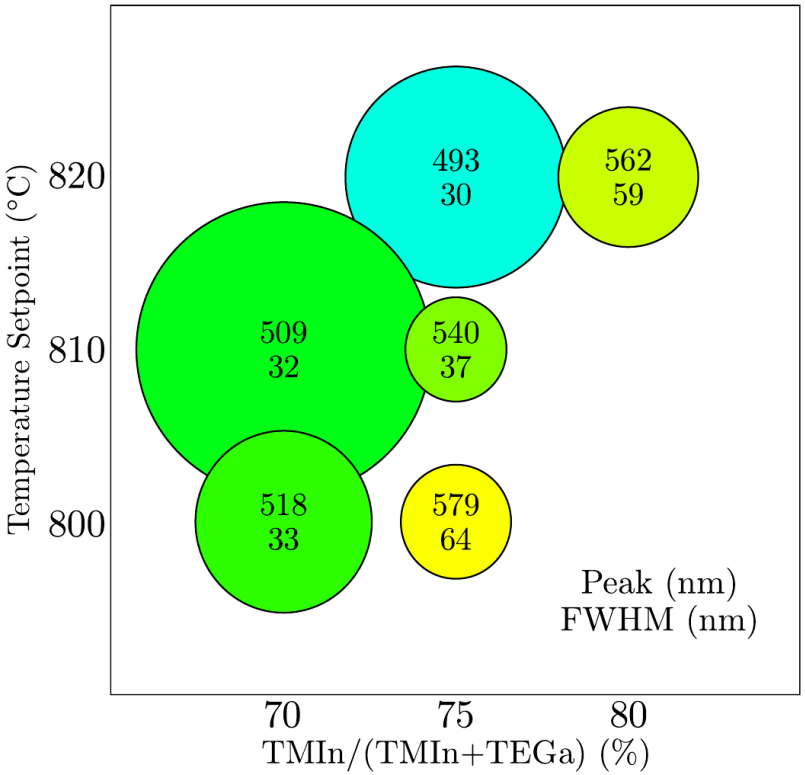


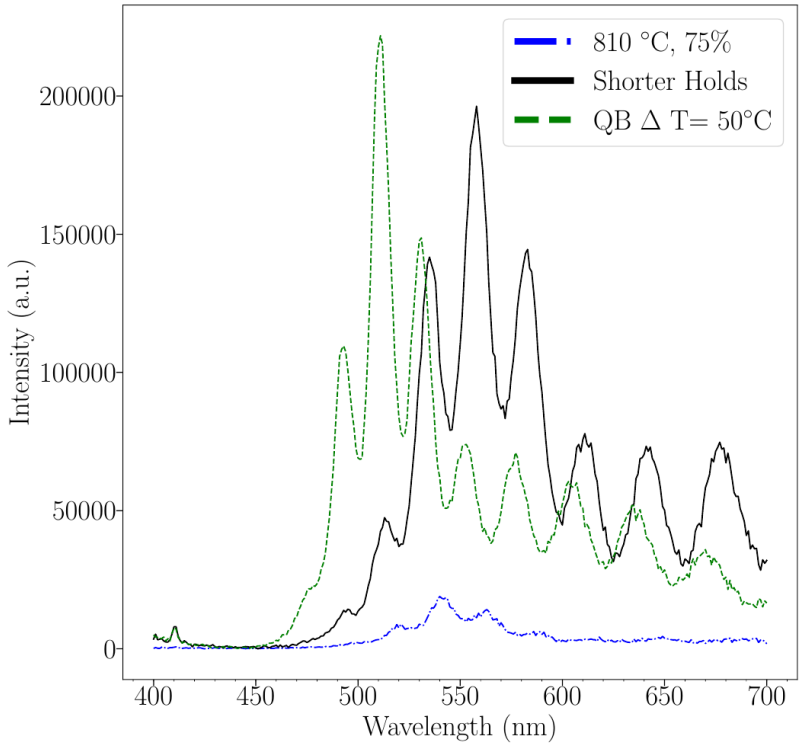
- Reducing hold times at interfaces and higher GaN quantum barrier growth expected to improve quality
- Initial experiments indicate improved photoluminescence

Lessons Learned

- The X'Pert 2 diffractometer will lie to you about reciprocal space map times. 3°×3° RSMs at 0.01° resolution takes 3 hours, not 100.
- Choose stiff AFM tips for hard specimens. This reduced AFM errors for us.
- X-ray superlattice fringes exist and we should look for them.
- Gallium bubbles in TEM, something we've yet to address.

Conclusions





- Established initial process parameters for green MQW on Si LED recipes
- Characterized specimens using SEM, XRD, AFM, PL, and two in TEM.
- Recipes may be improved upon in future optimizations

Thank you!

We'd like to especially thank:

- Xiaoqing, Michael Grundmann, and Dong Lee, for everything
- Arturas Vailionis for help with X-ray diffraction
- Juliet Jamtgaard for help with TEM
- Andrey Malkovskiy for help with AFM
- The Brongersma and McGehee labs, especially Dan Slotcavage and Eli Wolf, for help with their photoluminescence setup