UCSB

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Improved Characteristics of UV Optoelectronic devices on reduced defect density GaN layers

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APPLICATIONS/INTRO

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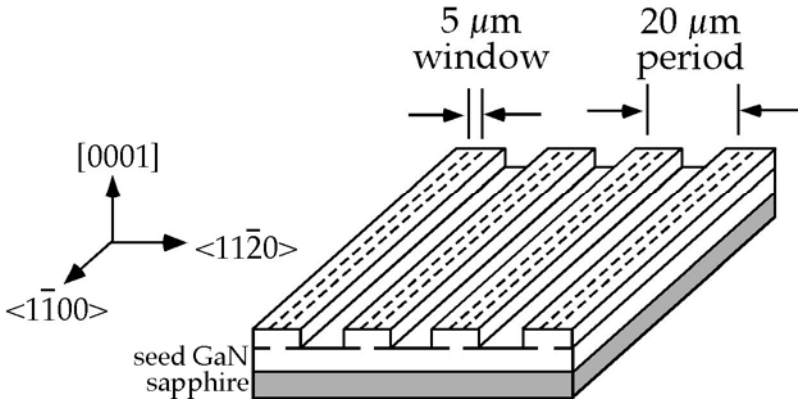
UV lasers are needed for

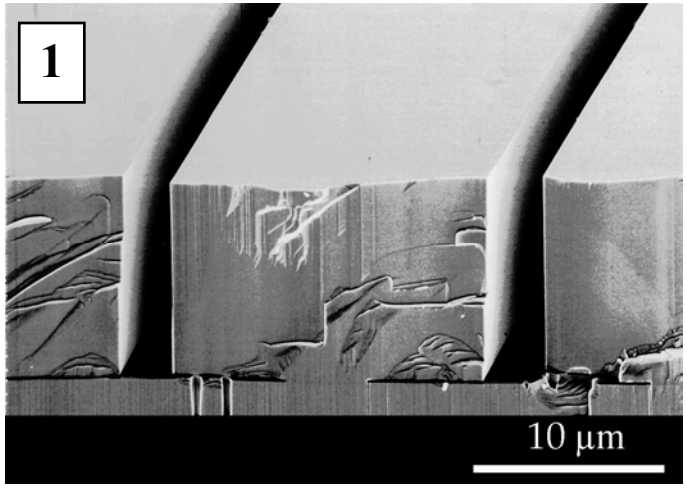
- Bio/chemical reagent detection 280nm fluorophores, DNA sequencing 480nm
- Daytime laser targeting and missile guidance
- Low Defect density layers are needed GaN and low In containing active regions
- Lasers on LEO GaN have a internal efficiency of ~22% compared to ~3% for lasers on sapphire

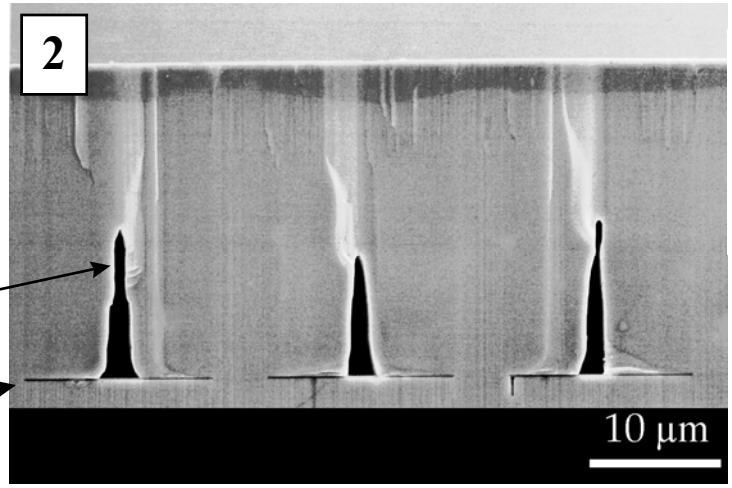
Low Defect Density Materials via LEO

2-Step Growth Approach:

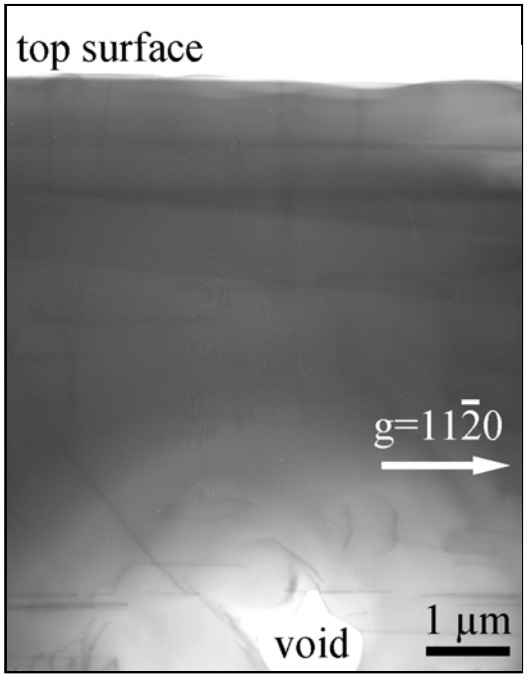
1. Grow separated stripes
2. Coalesce & planarize

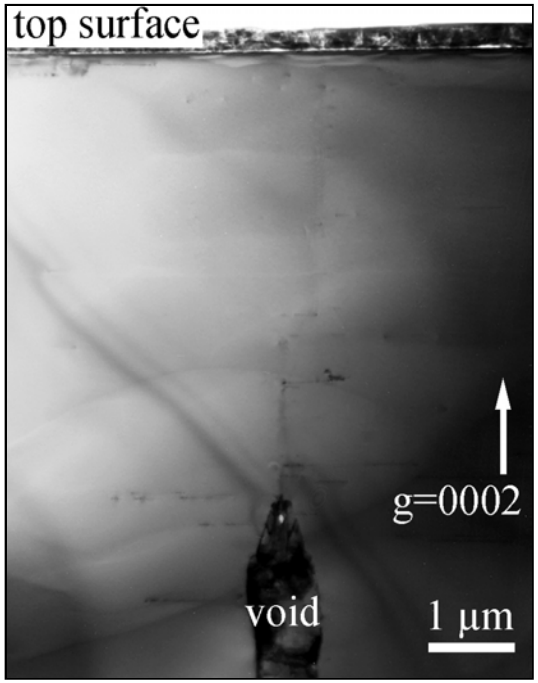


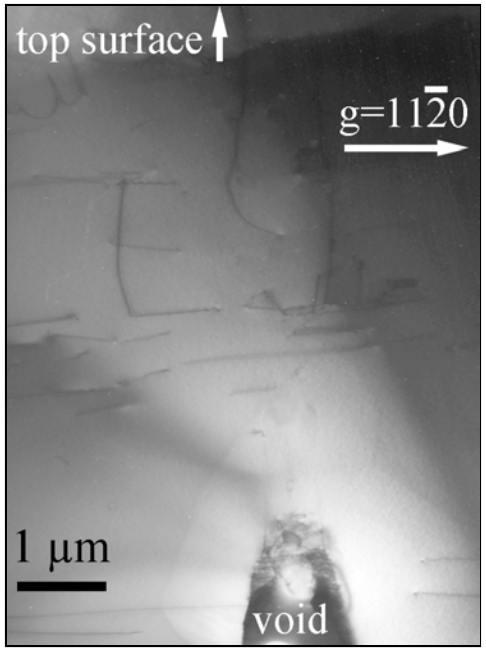




Coalescence Fronts: TEM

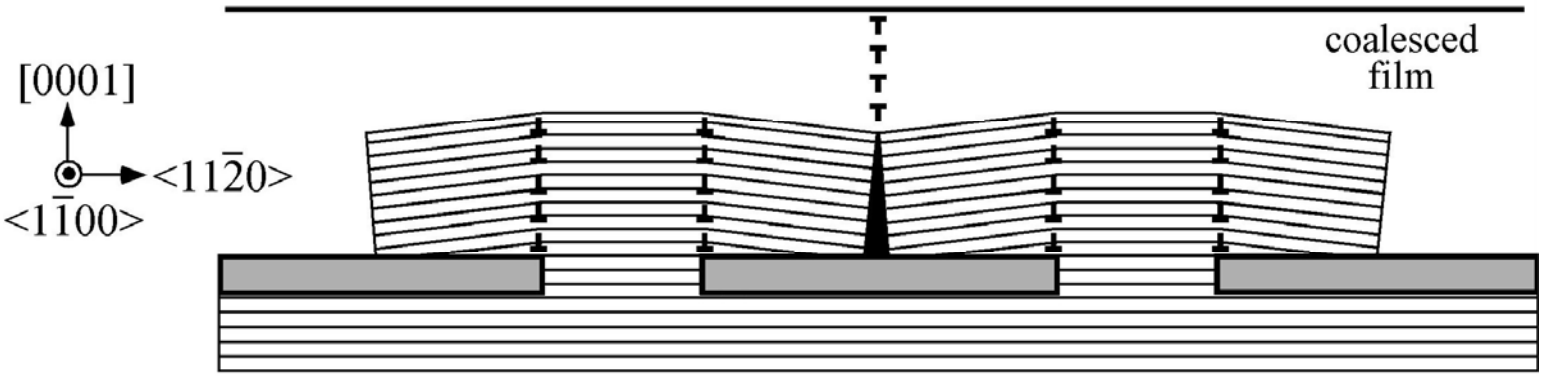


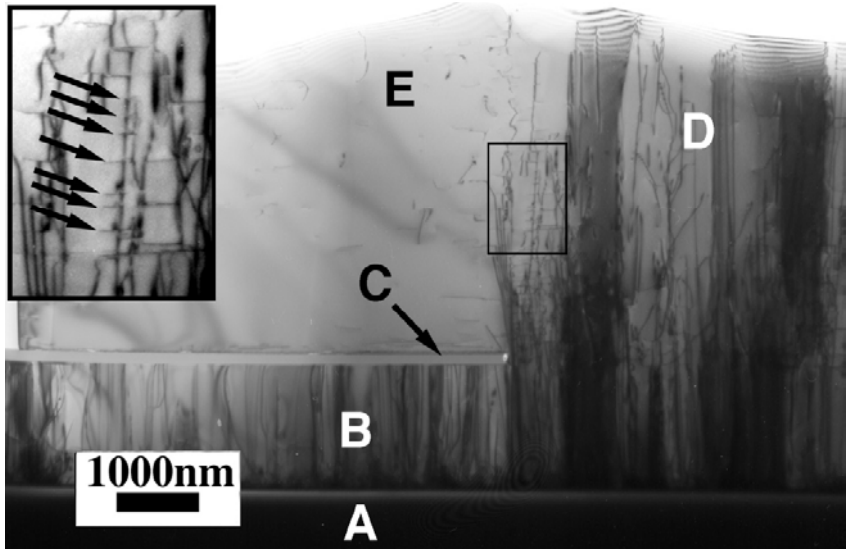




- Little or no threading dislocation generation at coalescence fronts.

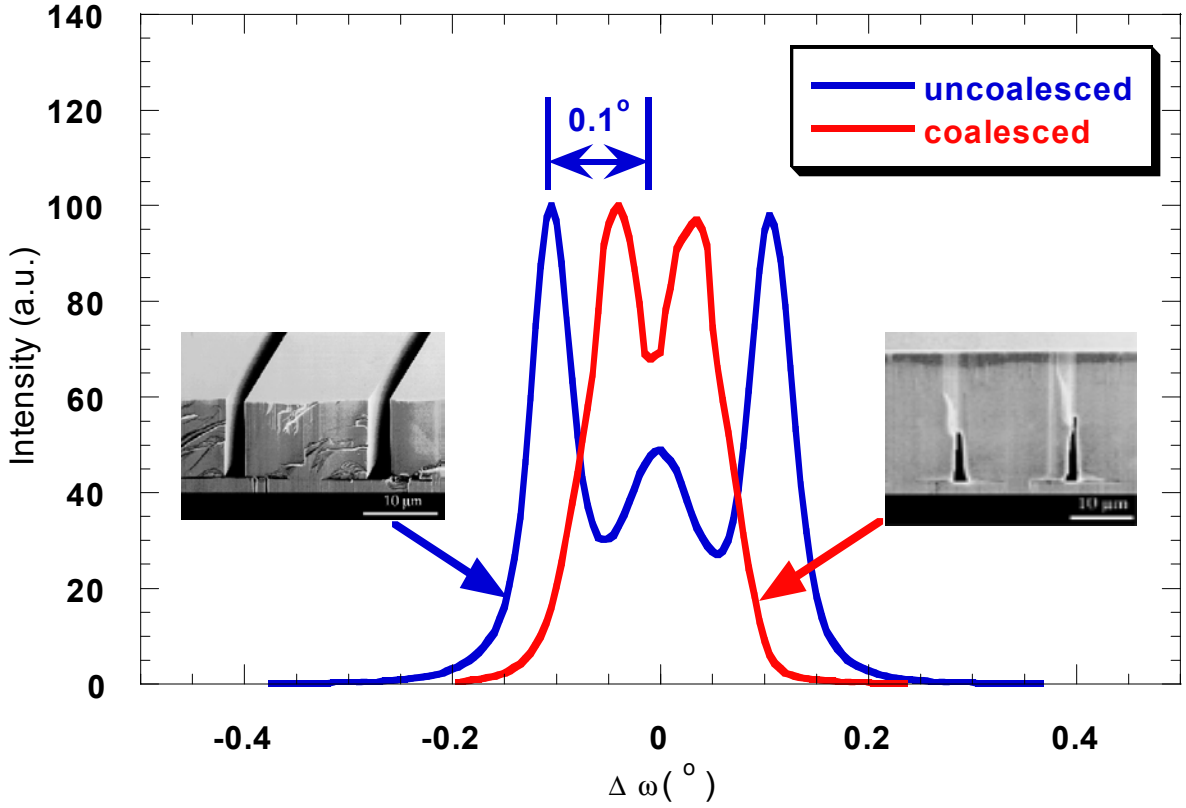
Eliminated Wing Tilt





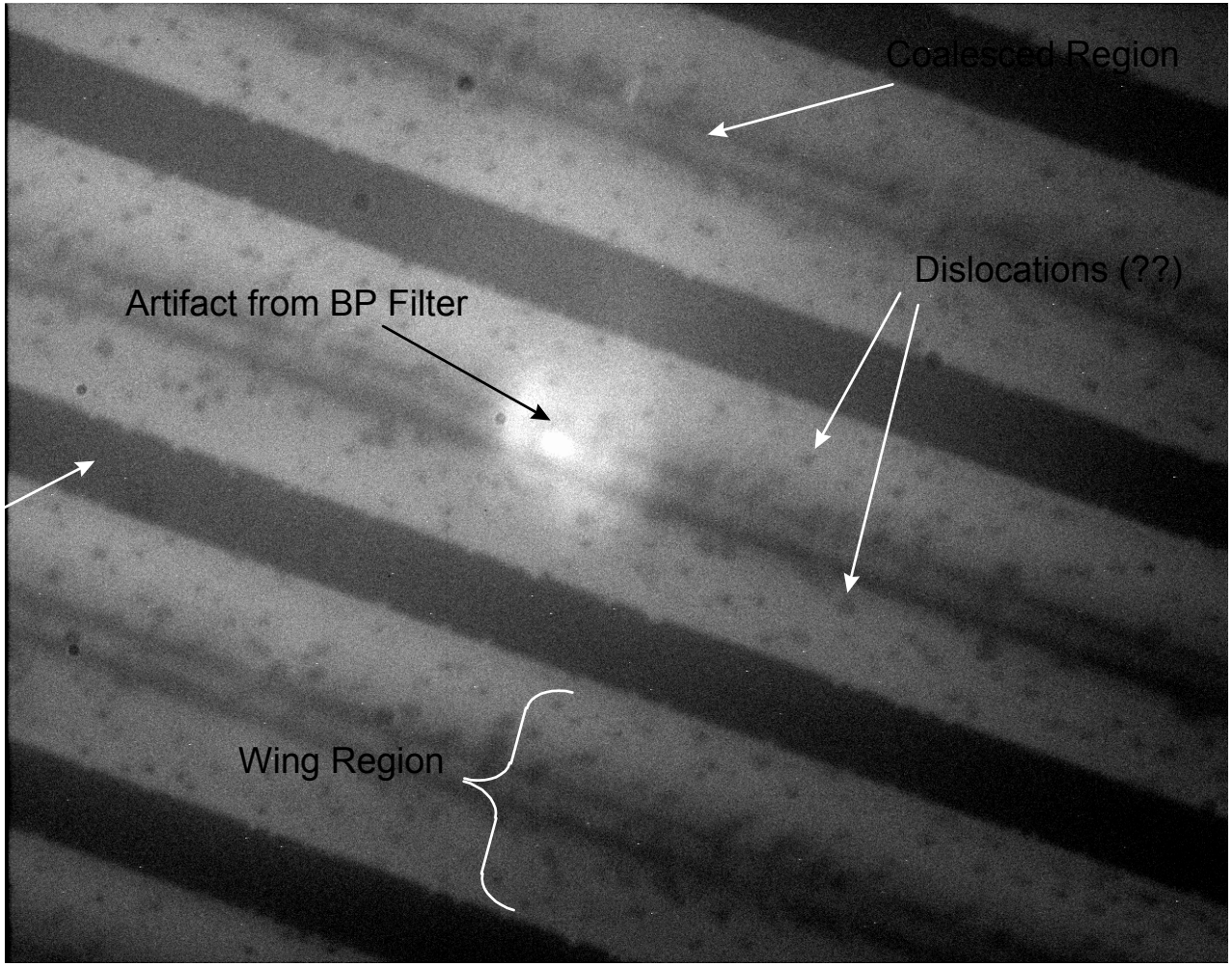
- Wing tilt causes formation of low-angle tilt boundary during coalescence
- Wing tilt causes problems with coalescence, large-area device processing

X-ray Diffraction Measurements

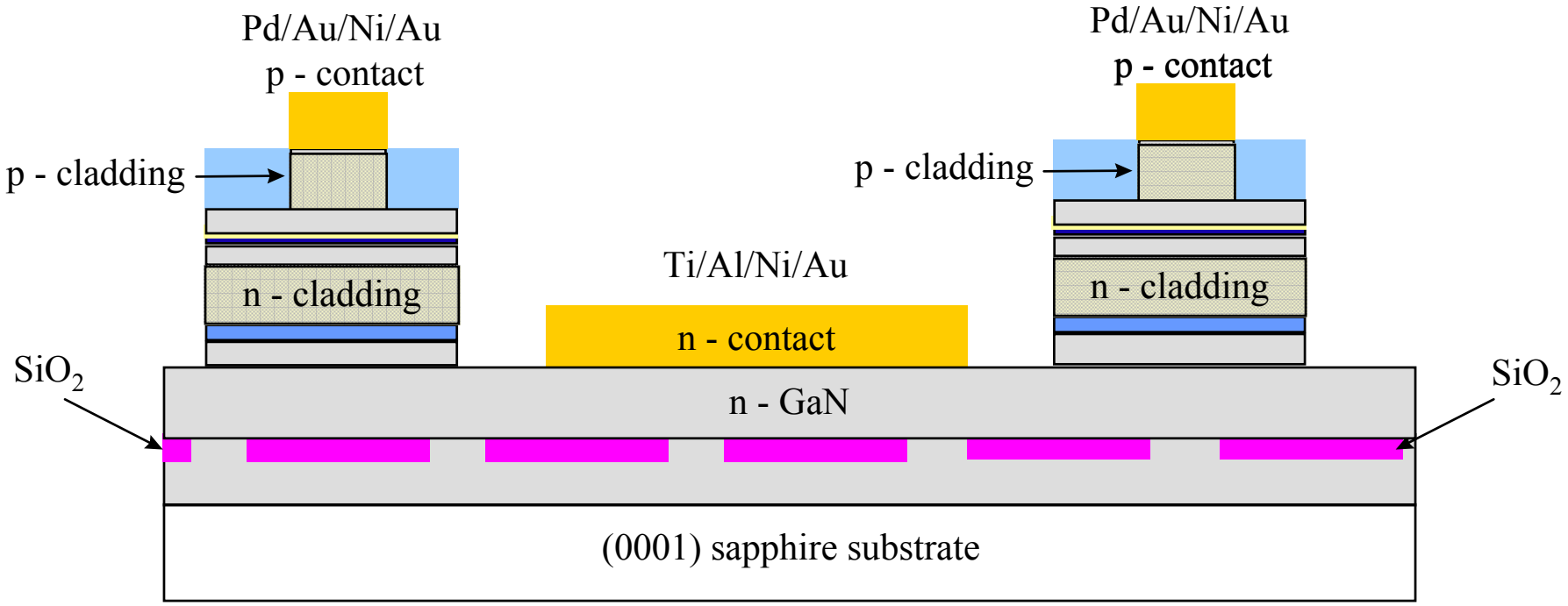


- Wing tilt observed for separated stripes is reduced after coalescence.

362 nm UV-PL Image of UCSB InGaN MQW LEO Sample

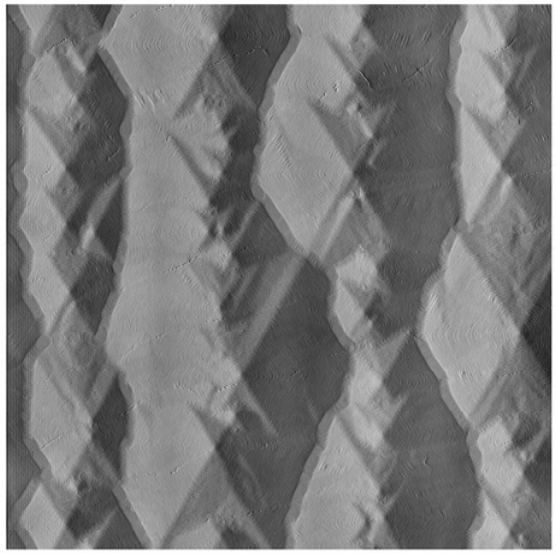


Device Structure on LEO Substrate

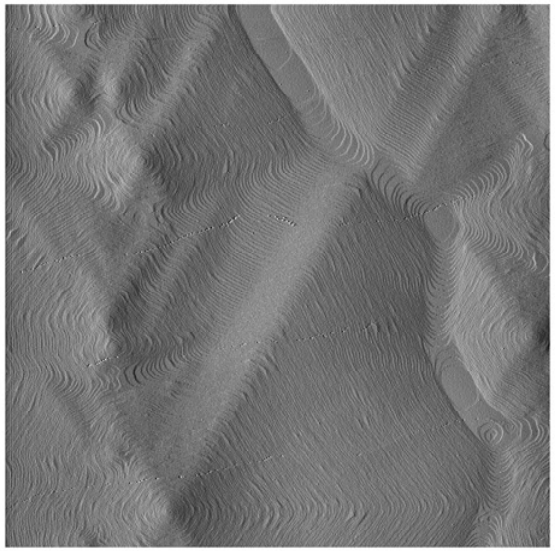


- The laser diode structure was placed above the wing regions, the coalescence fronts, and the seed regions.

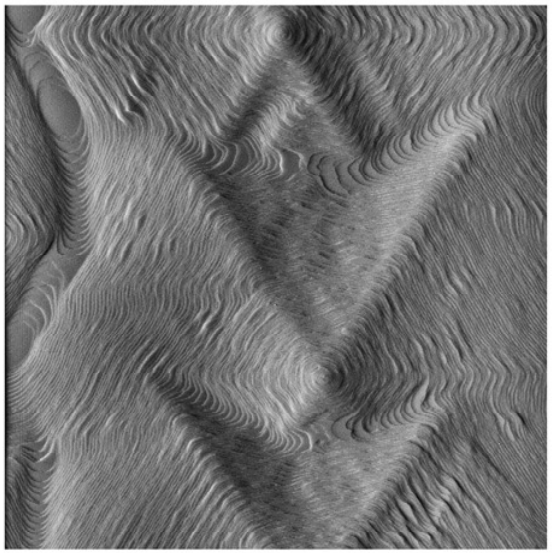
AFM of Laser Structure on LEO



75 x 75 μm



25 x 25 μm

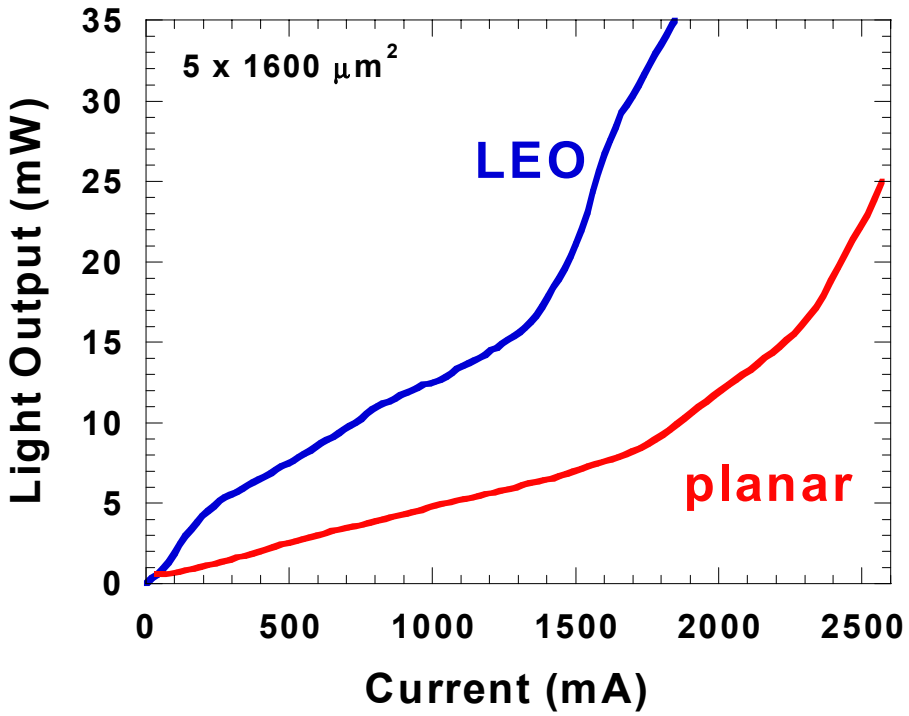


20 x 20 μm

Amplitude Images

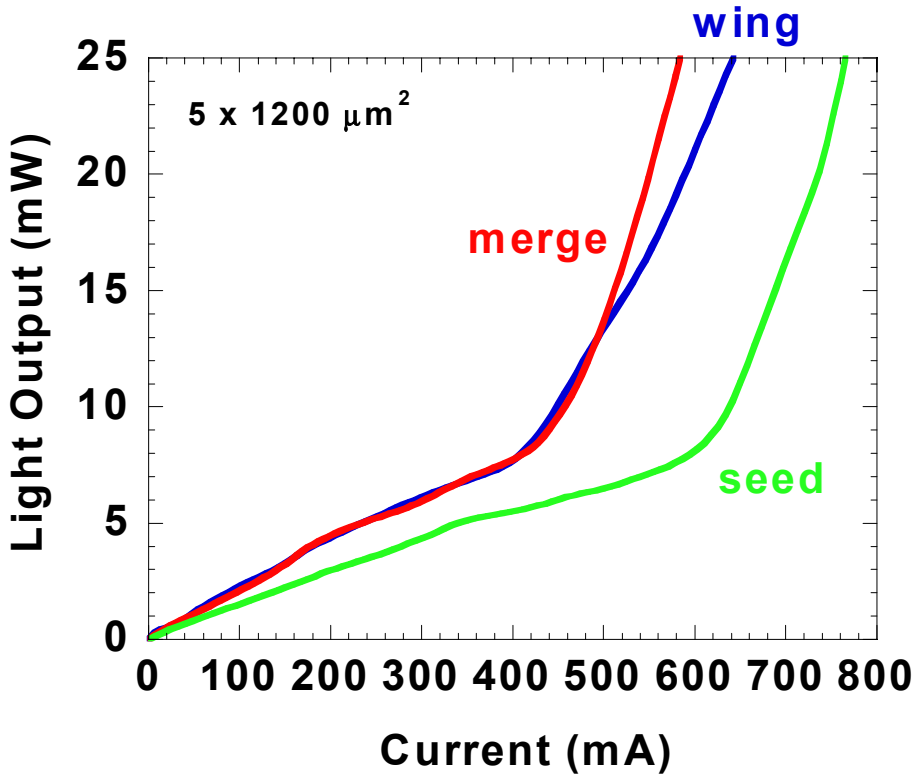
- Spirals are initiated in the dislocated window region and grow outward in the nearly-dislocation-free wing regions until another spiral is reached.

LEO and Planar Laser Comparison



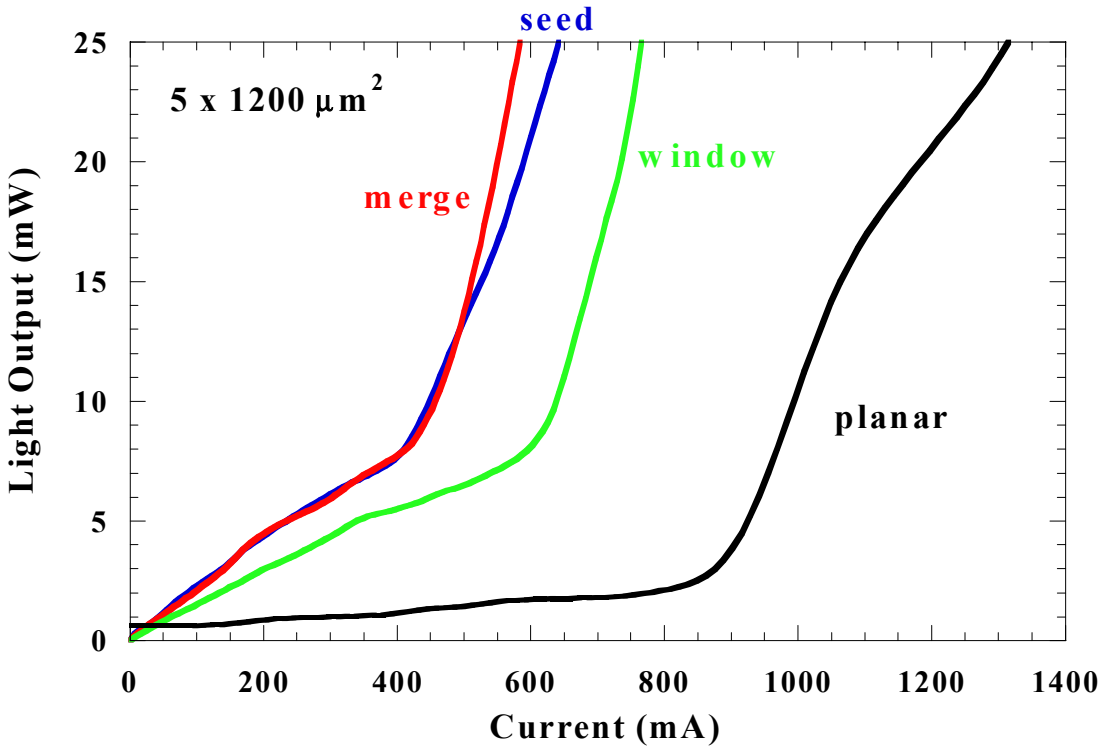
- Threshold current density was reduced by a factor of 2 from 10 kA/cm^2 for laser diodes grown on sapphire substrates to 4.8 kA/cm^2 for laser diodes grown on (LEO) GaN on sapphire.

LEO Laser Comparison



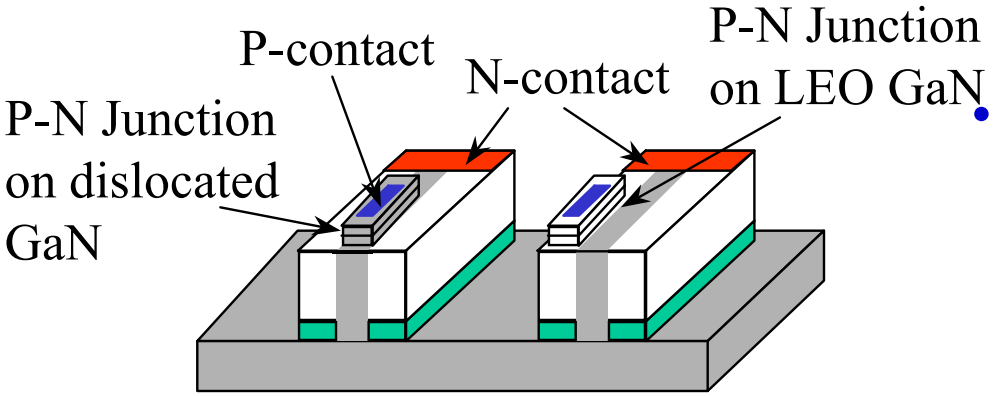
- Threshold current densities were reduced from 8 kA/cm^2 for lasers on the seed region compared to 3.7 kA/cm^2 for lasers on the wing regions.

LEO-Planar Laser Comparison



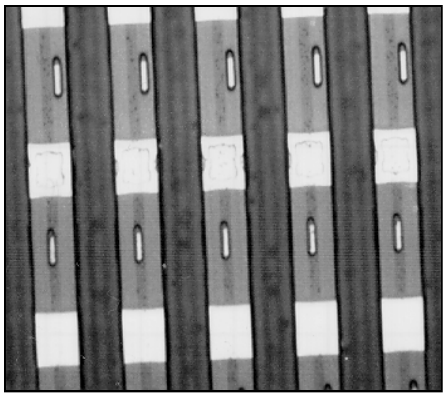
- There is a reduction in threshold current for lasers placed on the window region compared to lasers on planar GaN
  - Reduction of dislocations occurs with increased thickness involved in LEO process.

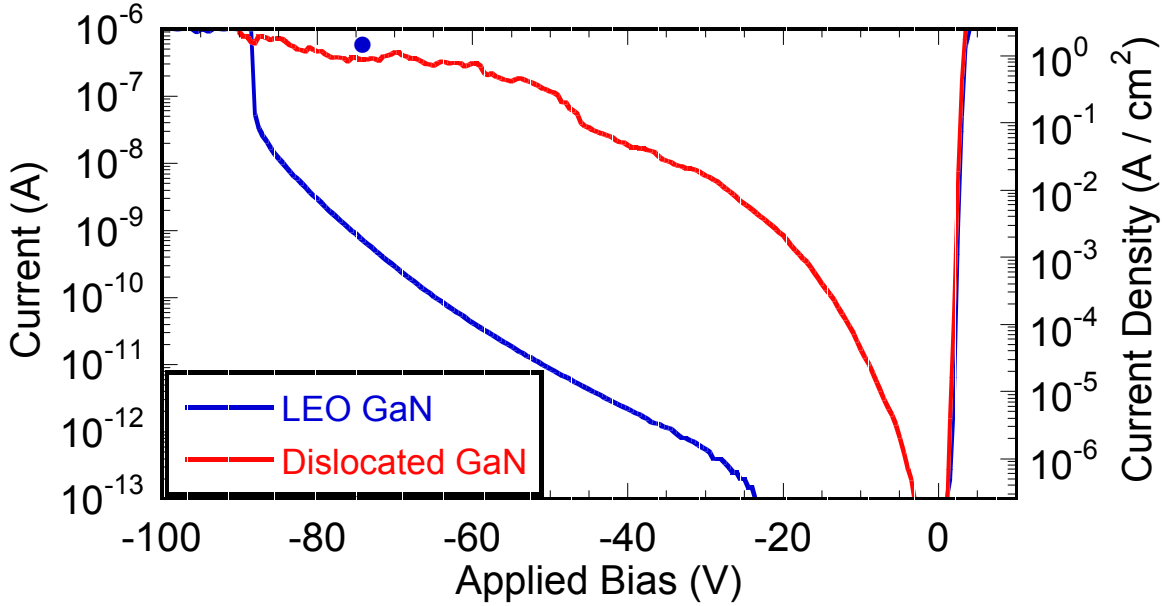
P-N Junctions on LEO GaN



Device Structure

Removing dislocations dramatically lowers leakage current in reverse-biased p-n junction.

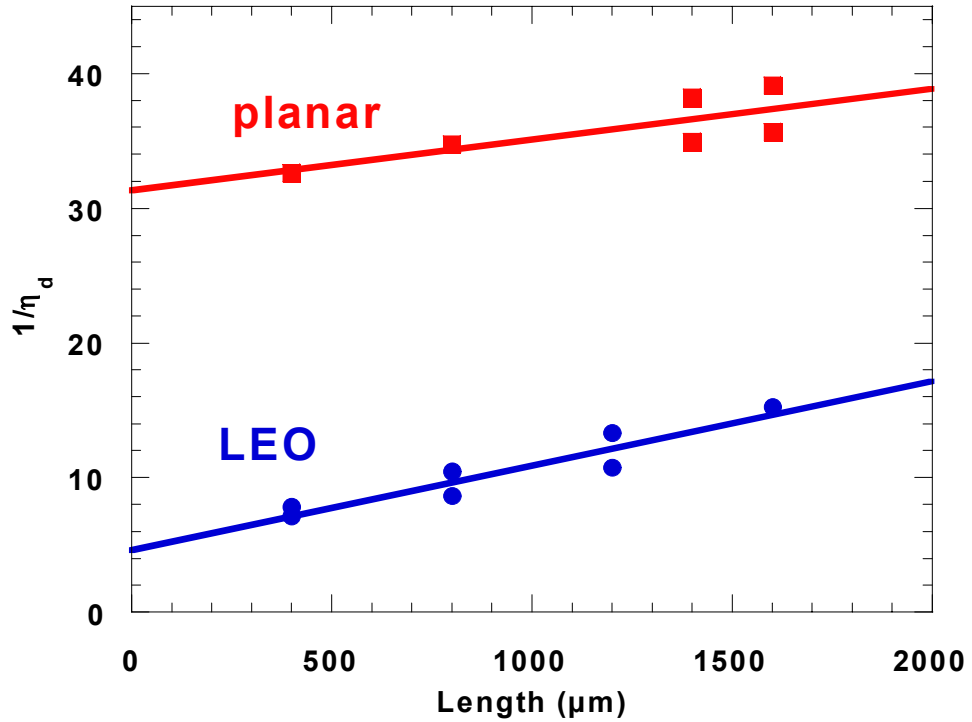




$$\eta_d = \eta_i \frac{\alpha_m}{\langle \alpha_i \rangle + \alpha_m}$$

$$\alpha_m = \frac{1}{L} \ln\left(\frac{1}{R}\right)$$

$$\frac{1}{\eta_d} = \frac{\langle \alpha_i \rangle}{\eta_i \ln\left(\frac{1}{R}\right)} L + \frac{1}{\eta_i}$$



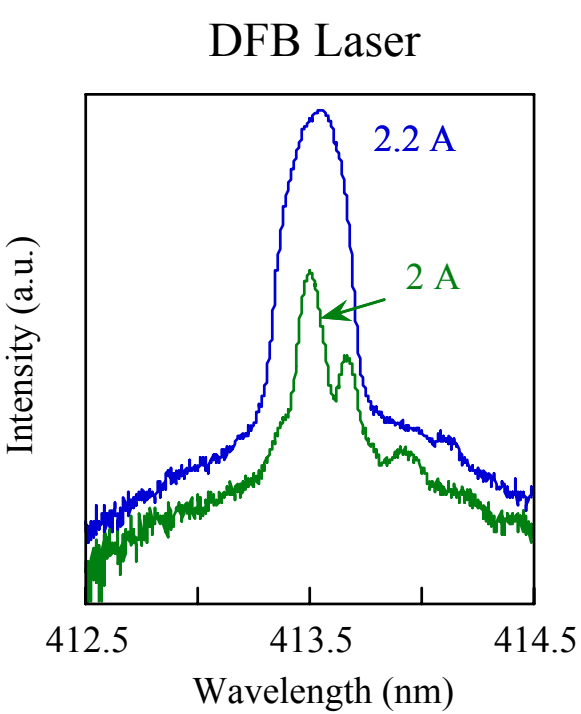
Efficiency

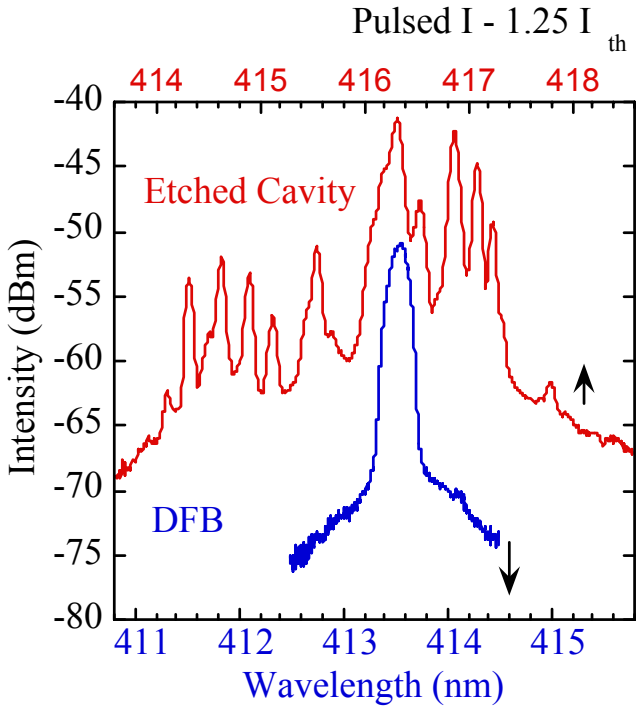
$$\eta_d = \eta_i \frac{\alpha_m}{\langle \alpha_i \rangle + \alpha_m}$$

As: $\eta_d \uparrow$ $\eta_i \uparrow$ $\alpha_i \downarrow$

- Lasers on LEO GaN have a internal efficiency of ~22% compared to ~3% for lasers on sapphire.
- This is due to a reduction of non-radiative recombination from a reduced threading dislocation density.

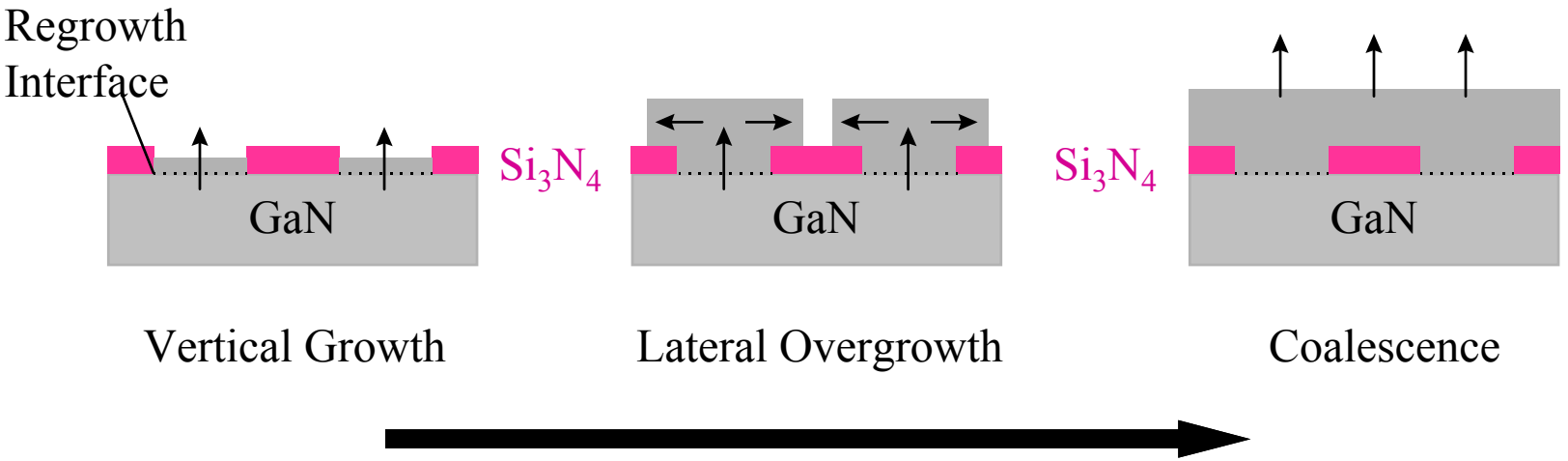
Spectrum of DFB Laser Diode

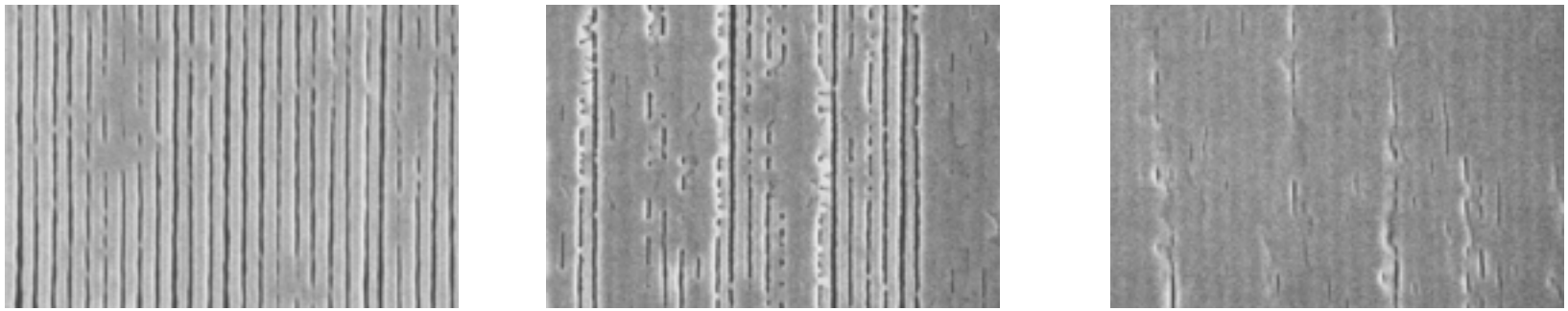




DFB laser shows narrow spectrum due to grating filter where etched cavity laser has considerable spectral broadening.

Lateral Overgrowth of Si_3N_4 gratings



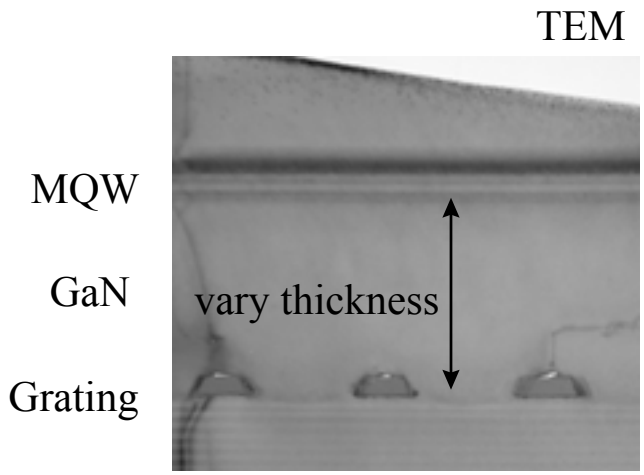


1 µm

$<1\bar{1}00>_{GaN}$

4 x 6 µm Plan-view SEM

Coalescence Technique



Imaging Conditions: $\vec{g} = < 0002 >$

Pattern grating along $<1\bar{1}00>_{GaN}$.

Begin regrowth with varying thicknesses of GaN in order to study coalesce.

Deposit InGaN multiple quantum well (MQW) above GaN.

X-ray diffraction measurements allow sensitive probe of the MQW interface roughness.

Conclusions

- InGaN UV multi-quantum well laser diodes have been fabricated on fully coalesced laterally overgrown GaN on sapphire.
- Threshold current density was reduced by a factor of 2 from 10 kA/cm^2 to 4.8 kA/cm^2 for laser diodes grown on LEO GaN on sapphire as compared to laser diodes on sapphire.
- DFB laser with significantly narrower spectrum would achieved
- For <400nm Emitters a reduction in nonradiative recombination from a reduced dislocation density leads to a higher internal efficiency.
- Further defect reduction with LEO, or AlN or GaN substrates is needed

For viable 280nm lasers