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Veeco D-125 MOCVD system

The growth of vertically conducting AlGaN heterostructures on patterned GaN substrates

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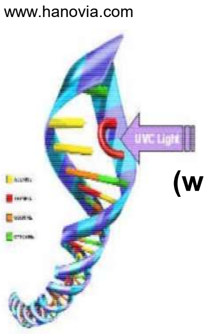
Outline

- Introduction
- Growth of $Al_xGa_{1-x}N$ (X = 0.3) on patterned N-GaN substrates
  - Pattern geometry and growth conditions
  - Threading dislocation density
- Summary

AlGaN Alloys Span UV-A, -B and –C Spectrum

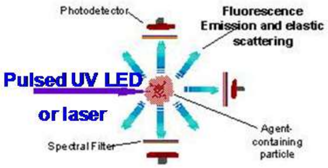


www.hanovia.com

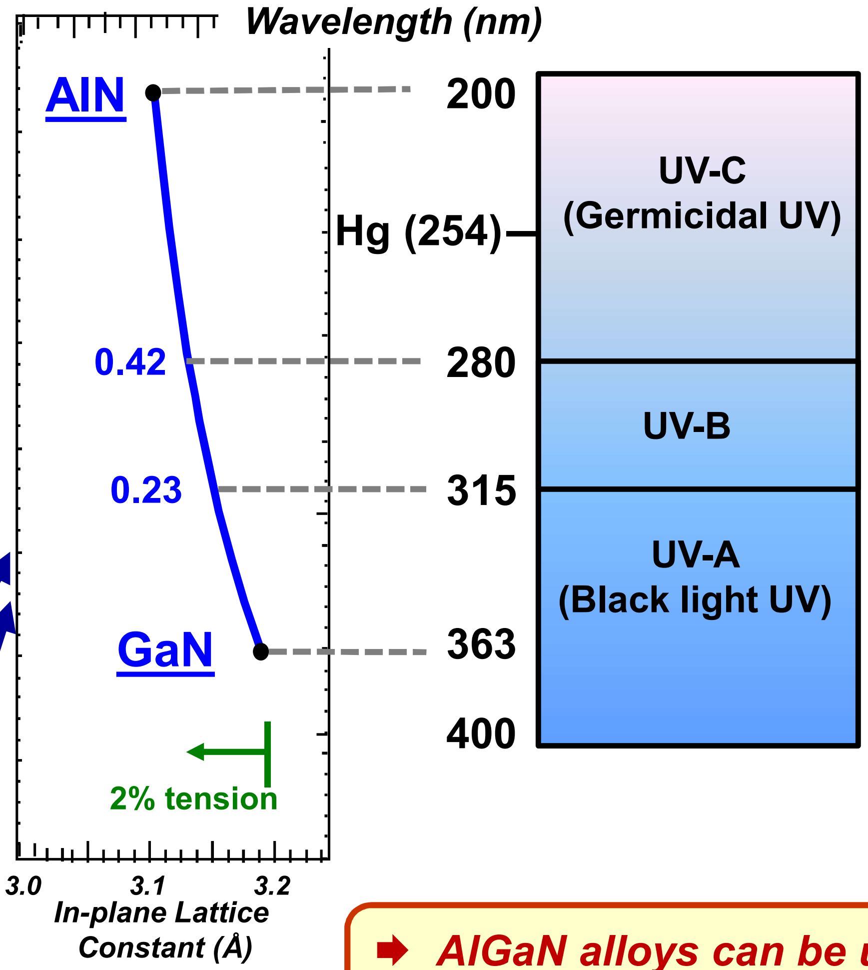
Germicidal
260-275 nm
(water, air, surfaces)

Solar-blind flame detection, λ<280 nm
(launch, fire)

UV-Induced Fluorescence
340, 280 nm
(biological agents)



UV Processing
300-360 nm
(inks, epoxy)



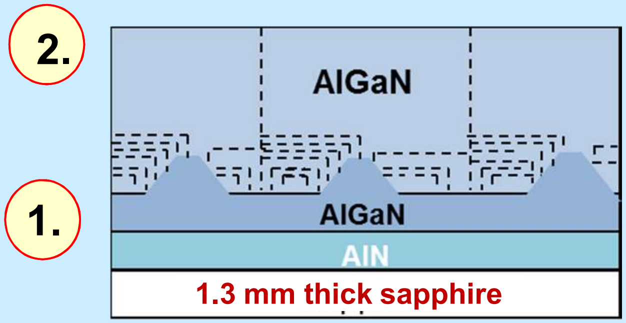
➡ ***AlGaN alloys can be used for UV-emitters and detectors***

Sandia's AlGaN overgrowth of patterned templates

AlGaN Growth on Patterned Templates

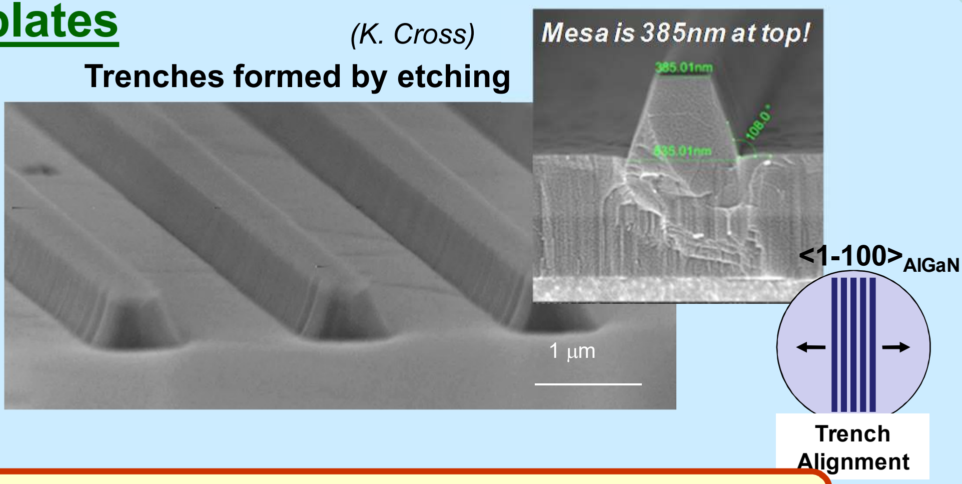
Allerman et. al., JCG 2014

AlGaN with reduced dislocations



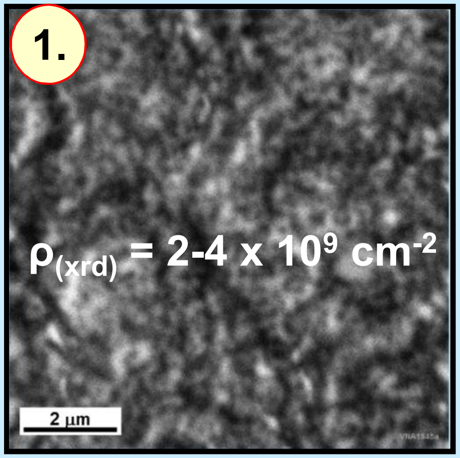
(K. Cross)

Trenches formed by etching

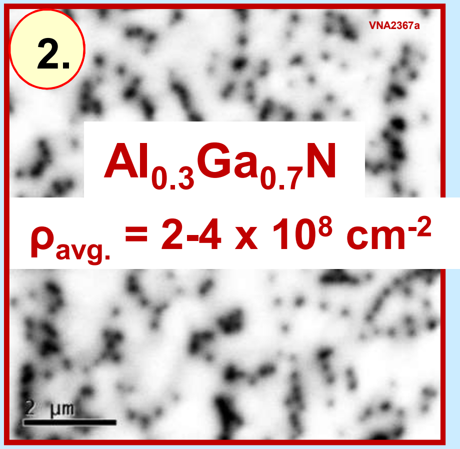


➡ ***Sub-micron features are key innovation for uniform reduction of dislocations***

Cathodoluminescence *(L. Alessi)*



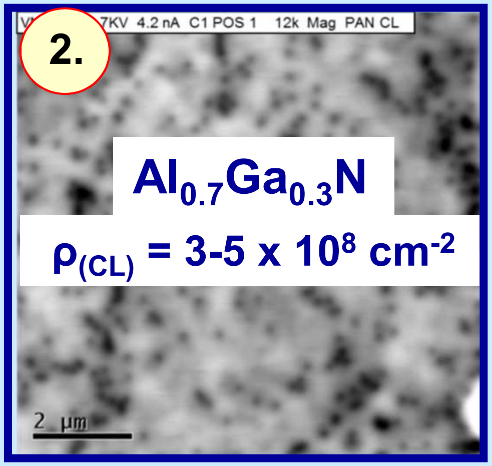
$\rho_{(xrd)} = 2\text{-}4 \times 10^{9}\ cm^{-2}$



$Al_{0.3}Ga_{0.7}N$

$\rho_{avg.} = 2\text{-}4 \times 10^{8}\ cm^{-2}$

10-20X reduction



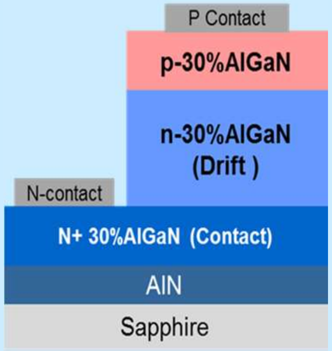
$Al_{0.7}Ga_{0.3}N$

$\rho_{(CL)} = 3\text{-}5 \times 10^{8}\ cm^{-2}$

10-15x reduction

Low on-resistance requires vertical geometry diode

Vertical

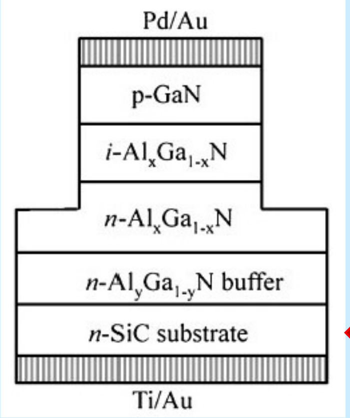


Quasi-vertical

- **Quasi-vertical geometry useful for diode development**
  - **Growth, process & JTE design**
- **Quasi-vertical geometry results on high R_{on} due to current crowding under N-contact**
  - **High resistive losses, low currents**

➡ ***Develop vertically conducting AlGaN diodes***

57%-AlGaN PN diode on n-SiC



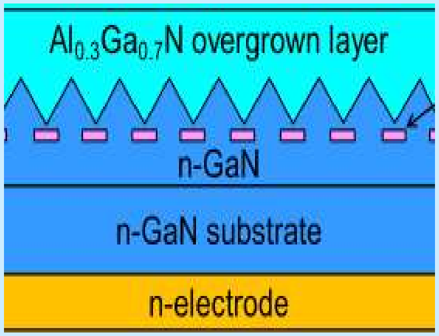
- **0.2 μm drift**
- **V_{br} < 200V**

R_{on}: 1.5 mΩ-cm^2

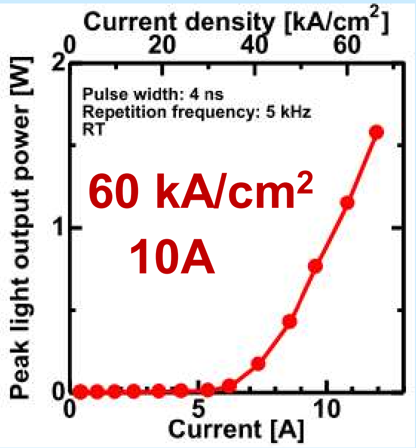
n-SiC

Nishikawa Jpn J. App. Phys. 2007

338 nm laser diode on n-GaN Substrates



Taketomi, Jpn J Appl Phys 2016

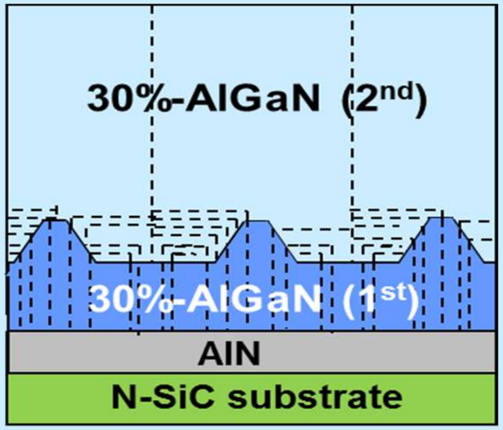


60 kA/cm^2

10A

Al$_x$Ga$_{1-x}$N overgrowth on conductive substrates

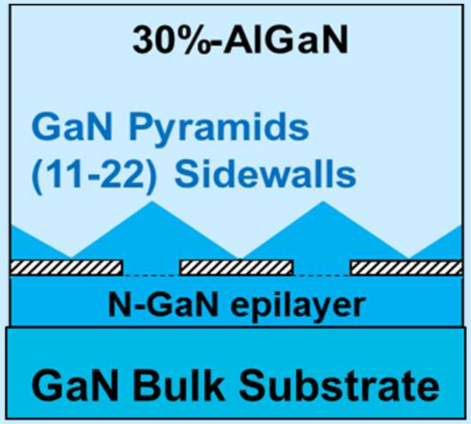
AlGaN on patterned n-SiC substrate



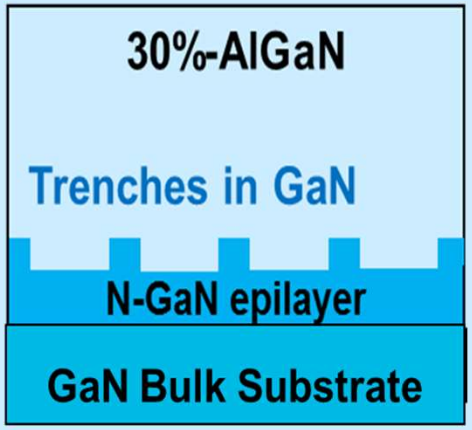
Sandia approach

- **Challenges:**
  - **tensile strain from thermal mismatch (cracking)**
- **Requires conductive nucleation layer (replace AlN)**

AlGaN regrowth on patterned n-type GaN substrates



Hamamatsu approach

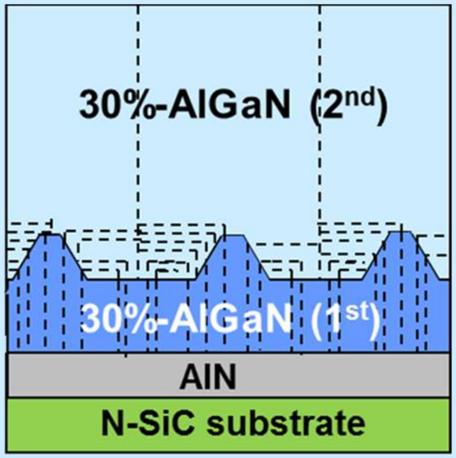


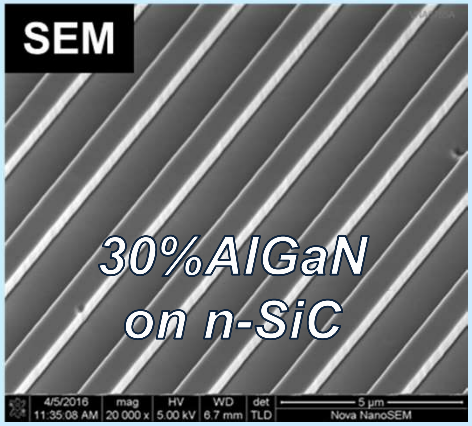
Sandia approach

- **Vertical UV-Laser diode demonstrated by Hamamatsu**
- **AlGaN growth on GaN trenches/pyramids is not straight forward**

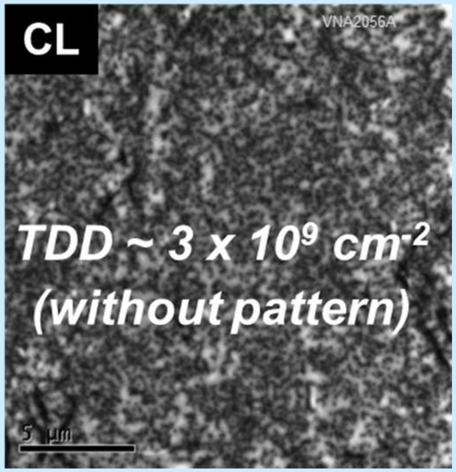
$Al_xGa_{1-x}N$ (X = 0.3) overgrowth on n-type SiC substrates

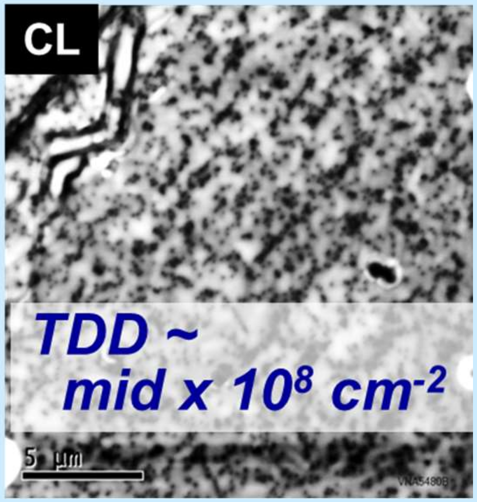
Epi Structure



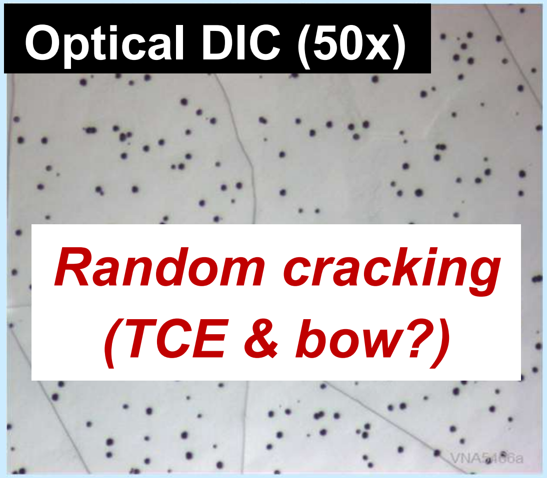


Defect Reduction





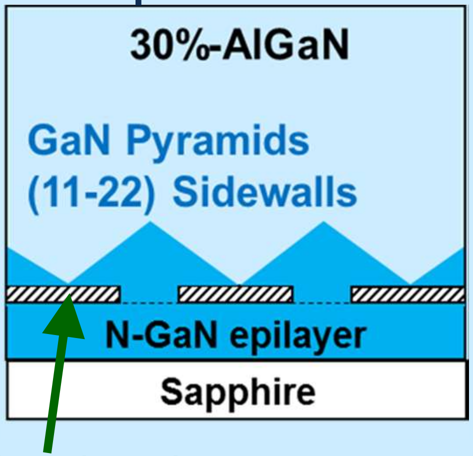
Surface Morphology



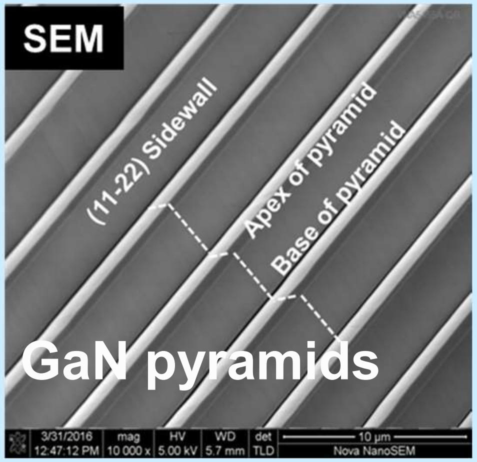
- ➡ TDD to mid x 10^8 cm^{-2}
- ➡ Random cracks in epi
  (Add compressive strain)
- ➡ Develop conductive
  nucleation layer

Al$_x$Ga$_{1-x}$N (X = 0.3) overgrowth on n-type GaN substrates (Hamamatsu)

Epi Structure

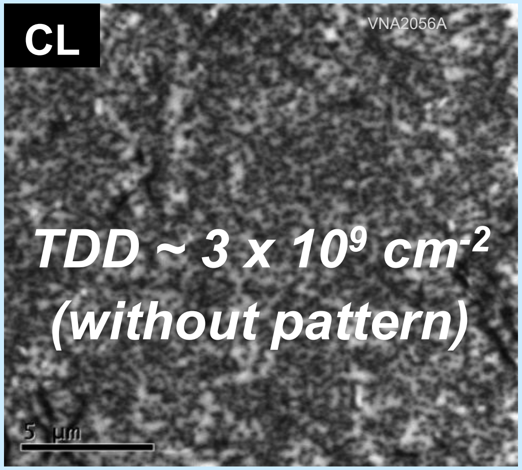


SiN$_x$ (3 µm) with 1 µm space

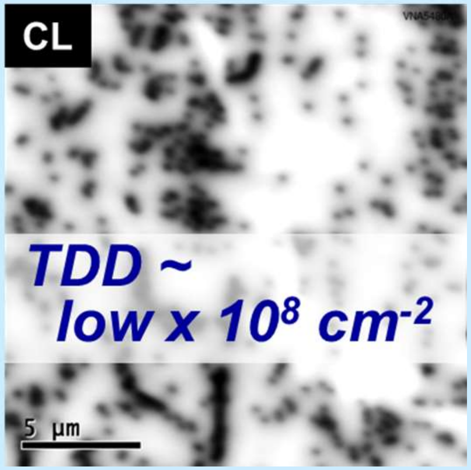


GaN pyramids

Defect Reduction

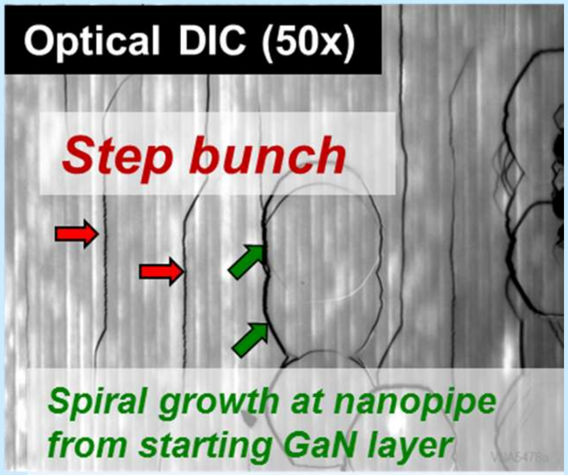


TDD ~ 3 x 10^9 cm^{-2} (without pattern)



TDD ~ low x 10^8 cm^{-2}

Surface Morphology

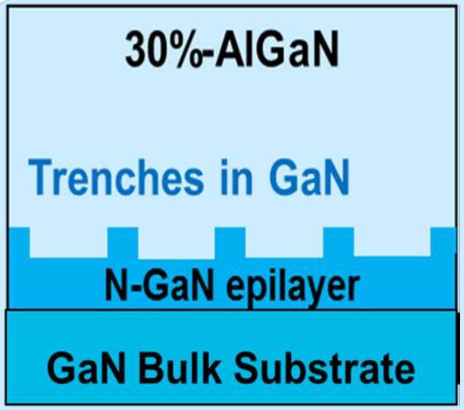


Step bunch

Spiral growth at nanopipe from starting GaN layer

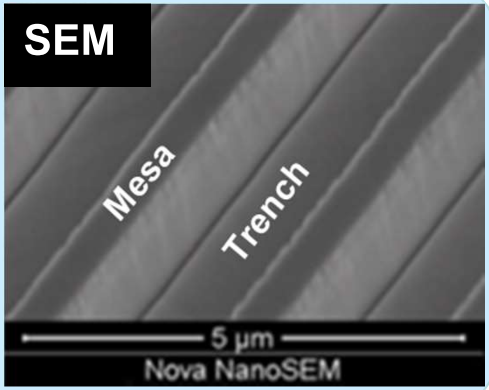
- ➡ Well formed GaN pyramid
- ➡ TDD to low x 10^8 cm^{-2}
- ➡ AlGaN overgrowth delamination from SiN$_x$

$Al_xGa_{1-x}N$ (X = 0.3) overgrowth on n-type GaN substrates



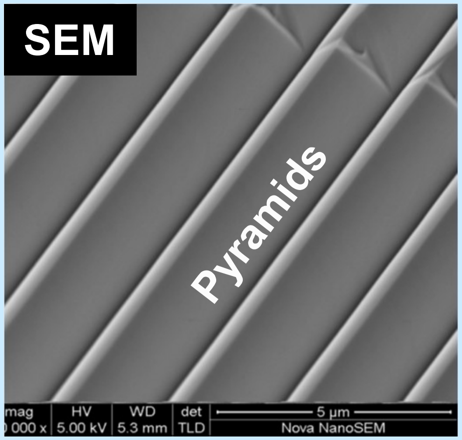
Patterned GaN substrate

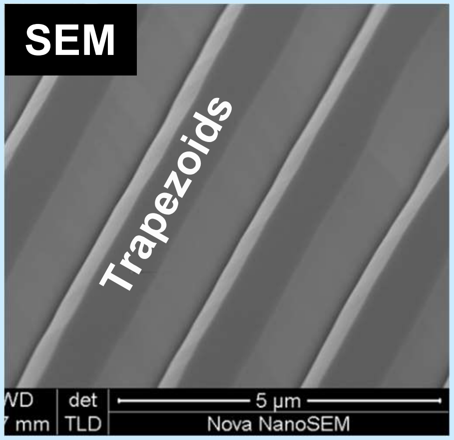
- **Investigated growth conditions:**
  - **➡ V/III, Temperature,**
- **Geometry: 1 μm (mesa) x 1 μm (trench)**
- **Etch depth: 0.4 to 1.2 μm**

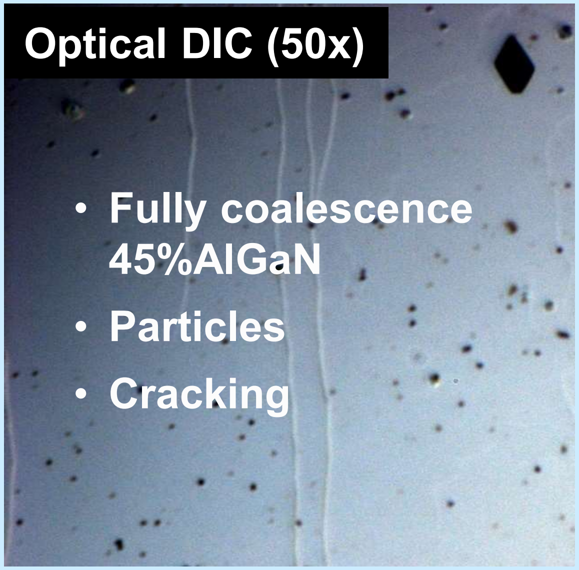


Growth initiation & AlGaN overgrowth

- **Facet control during growth enables manipulation of threading dislocations & planar surfaces**



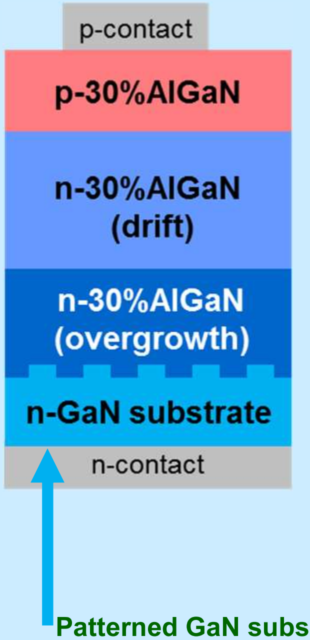




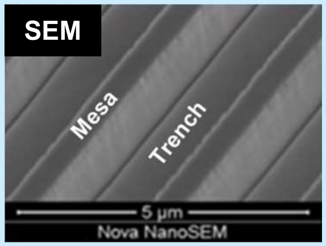
- **Fully coalescence 45%AlGaN**
- **Particles**
- **Cracking**

➡ Overgrowth on GaN to Xal = 0.45

Vertical $Al_{0.3}Ga_{0.7}N$ PN diode on a conducting GaN substrate

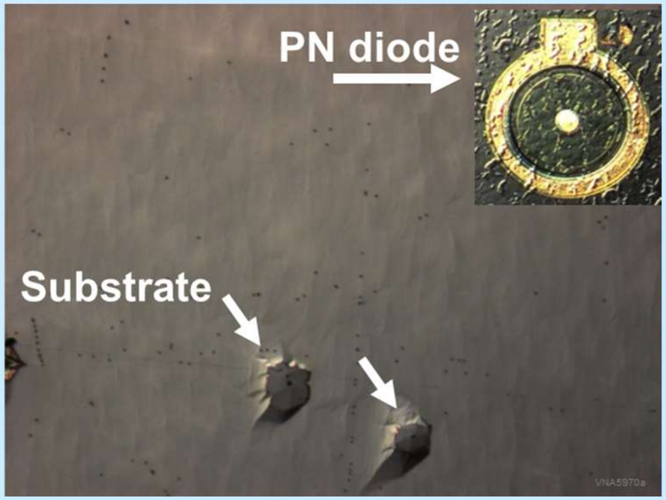


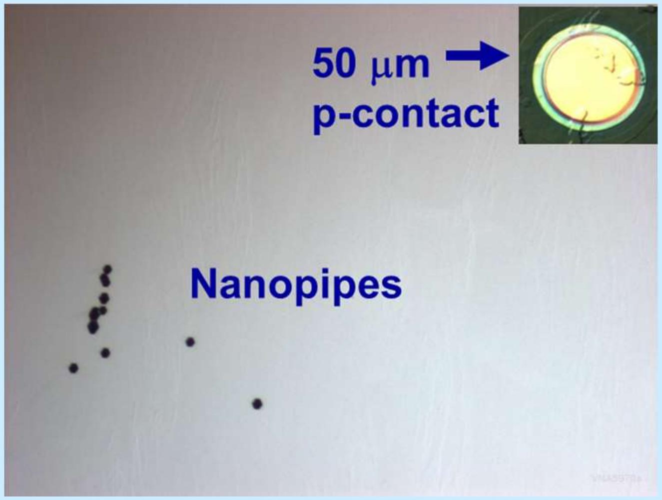
Patterned GaN substrate



● *Vertical PN in 30%AlGaN*

- **30%AlGaN pn diode now grown on a conducting GaN substrate**
- **Drift region:**
  Thickness: 5.8 μm
  N_o: 2-4 x 10^{16} cm^{-3}
- **30%AlGaN overgrowth:**
  Thickness: 6 μm
  N_o: 2-5 x 10^{17} cm^{-3}
- **Total epi: 12.4 μm**
  Little cracking
  Smooth morphology





Summary

- Successful overgrowth of $Al_xGa_{1-x}N$ on patterned N-GaN substrates to X = 0.45
- Overgrowth at higher compositions requires higher growth temperatures which decompose GaN substrate
- N-type SiC substrates are suitable for higher growth temperatures but epilayer cracking must be prevented