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Nanowire Templated Lateral Epitaxial Growth (NTLEG) of Low Dislocation Density GaN

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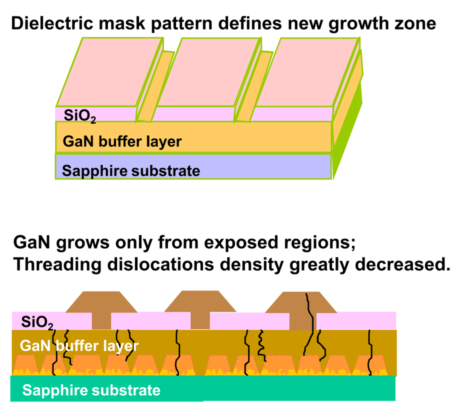
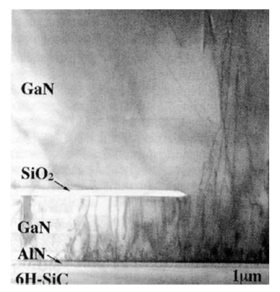
Background & Project Objectives

Background

Epitaxial lateral overgrowth (ELO) techniques currently employed reduce the dislocation densities of heteroepitaxial GaN. With lateral overgrowth techniques, typical dislocation densities in the 10^7 cm^{-2} range can be achieved in regions.



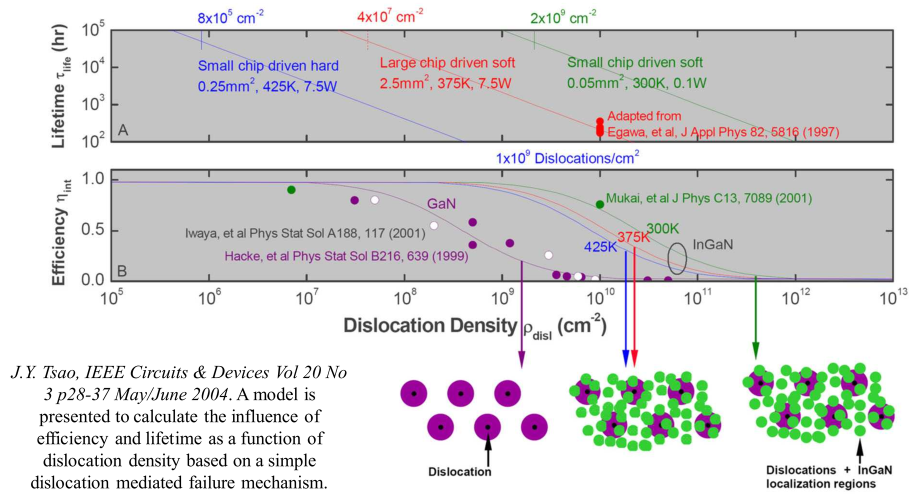


Defect density decreased from 10^9/cm^2 to less than 10^7/cm^2 above the masked regions only*

* Ref: T. Zheleva, O-H Nam, J. D. Griffin, M. D. Bremser, R. F. Davis, Mat. Res. Soc. Symp. Proc., 482, 393 (1998).

The main disadvantage of ELO techniques is cost. Due to process complexity, epitaxial cost is tripled or more, limiting use to more costly devices like blue laser diodes.

For high current opto-electronic applications, devices might degrade through common dislocation induced failure mechanism observed in other III-V semiconductor devices. ***At future, higher input power densities, dislocations ≤ 10^7 cm^{-2} may be required for acceptable lifetimes***



J.Y. Tsao, IEEE Circuits & Devices Vol 20 No 3 p28-37 May/June 2004. A model is presented to calculate the influence of efficiency and lifetime as a function of dislocation density based on a simple dislocation mediated failure mechanism.

Device lifetime increased on lower dislocation density GaN.

Objectives/Potential Benefits to SSL

In order to achieve these targeted efficiency and device lifetime goals, it will thus be necessary to provide low dislocation density GaN substrates and buffers that will allow fabrication of high power density, efficient LEDs with long lifetimes. Additionally, the **costs** of these substrates and buffers must be low enough to allow LEDs to be cost-competitive with other lighting technologies

Our objective is to develop a novel technique (**N**anowire **T**emplated **L**ateral **E**pitaxial **G**rowth, **NTLEG**) employing vertically aligned GaN nanowire arrays grown by metal-catalyzed metal-organic chemical vapor deposition (MOCVD) as high quality, **nano-compliant strain-relief templates for the lateral growth and coalescence of inexpensive, low dislocation density GaN films** (target ≤ 10^8 cm^{-2} for first eighteen months of project, eventual target ≤ 10^7 cm^{-2} range dislocations). Additionally, the NTLEG films will be *non-polar* due to their predicted orientation (11-20), making them more attractive for high-performance devices. In contrast to expensive epitaxial lateral overgrowth (ELO) processes, the NTLEG technique requires no lithographic patterning or GaN pre-growth steps.

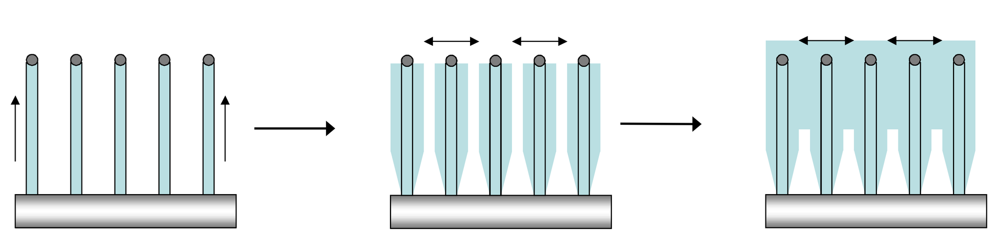
This proposal will impact **all aspects** of the DOE SSL mission by providing a novel technique (NTLEG) that will enable growth of high quality GaN buffers at a cost substantially lower than current ELO techniques. **This will enable cost-competitive, high power density, high efficiency LEDs with long lifetimes to be developed.**

Budget Period Milestones

Milestones	Description	Completion Time
Milestone 1	Growth, characterization, and optimization of GaN nanowire templates. Demonstration of high quality, vertical array of single crystal GaN nanowires across 2" r-plane sapphire.	Month 12
Milestone 2.1	Growth and optimization of NTLEG GaN films from vertical nanowire arrays grown without the use of a template. Optimize and demonstrate NTLEG films with dislocation densities ≤10^8 cm^{-2}.	Month 18
Milestone 2.2	Characterization of NTLEG grown GaN films using template-free GaN nanowire arrays.	Month 18
Milestone 2.3	Develop model for growth of NTLEG GaN films	Month 18

Project Elements and Technology

Overview of NTLEG Approach

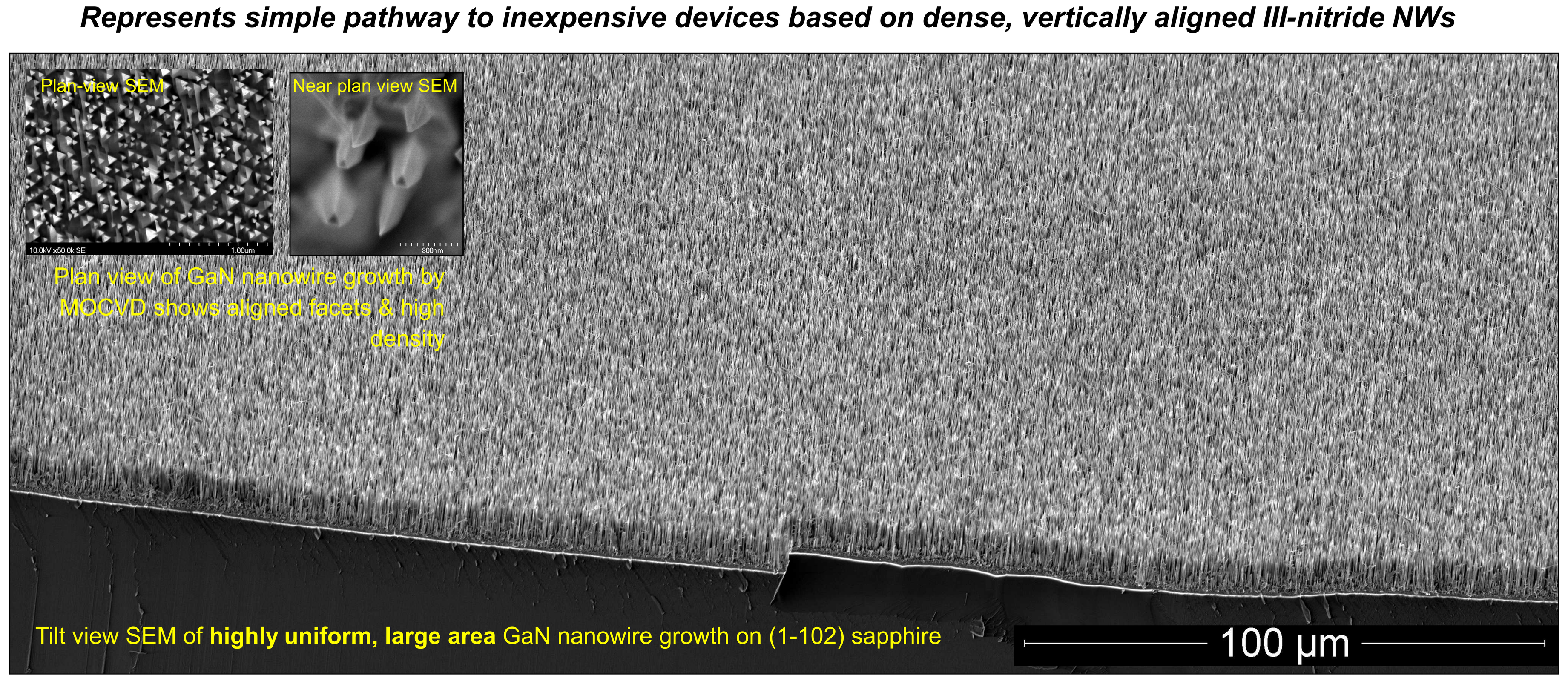


Advantages of NTLEG approach over ELO

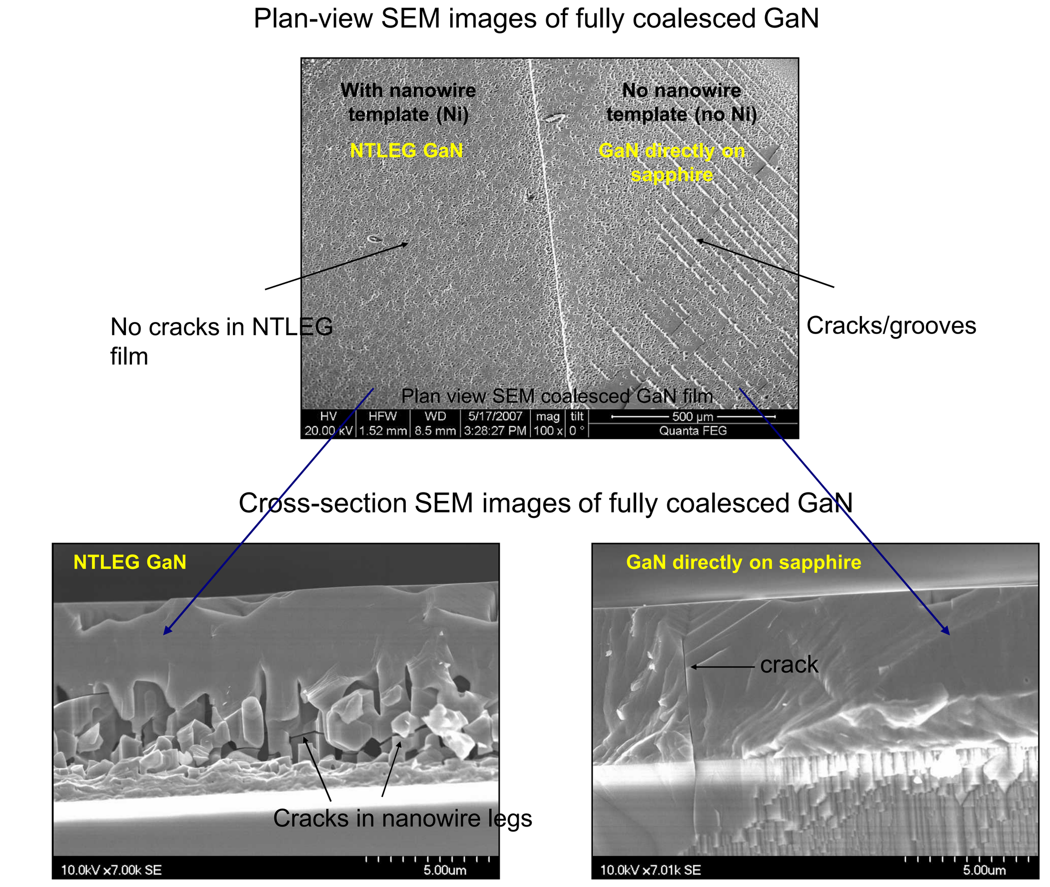
- High quality, low dislocation or dislocation-free nanowires as growth template directly on sapphire
- Nanowires serve as nanoscale bridges that connect epilayer and substrate, minimizing strain & reducing defects ("nanoheteroepitaxy")
- *No "unusable" areas* as in ELO
- *Lower cost*
  - Sapphire can be used (no GaN pre-growth required)
  - **No patterning or interruption of growth required**
- Results in *non-polar film* for non-polar nanowire orientation

Template-Free, Vertically Aligned Growth of GaN Nanowires on Sapphire

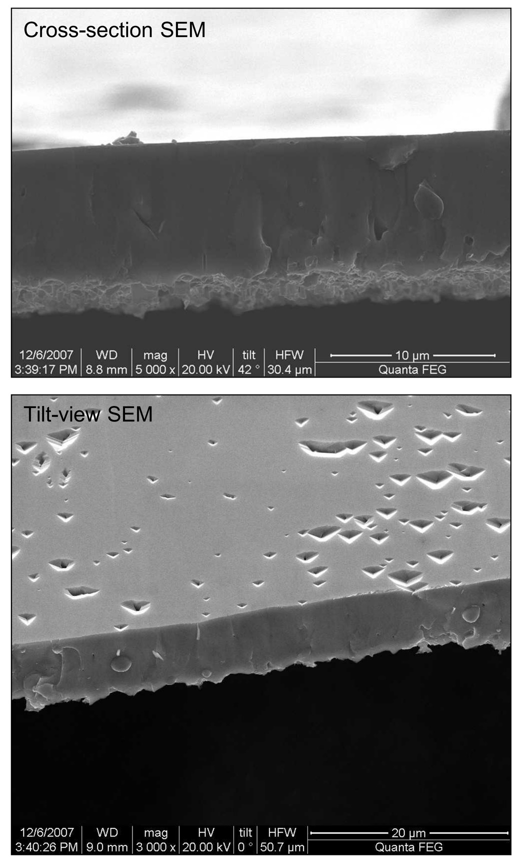
Represents simple pathway to inexpensive devices based on dense, vertically aligned III-nitride NWs



Proof of Concept Demonstrated: Fully coalesced NTLEG GaN films

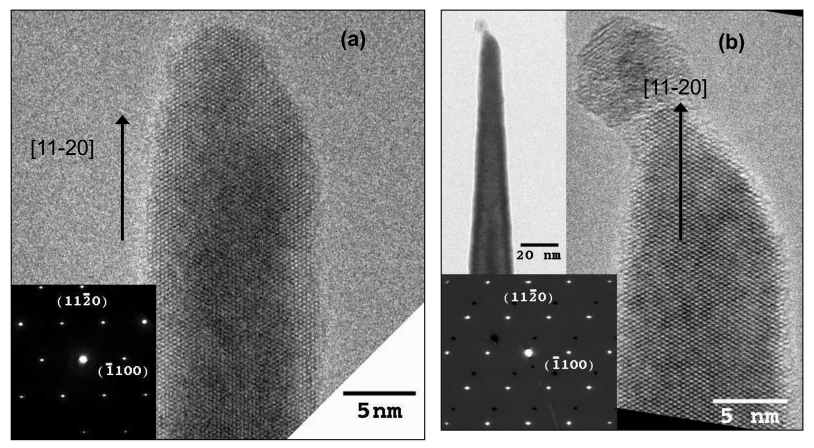


Fully coalesced freestanding NTLEG a-plane GaN



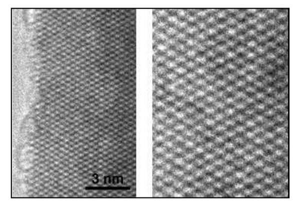
Strain is relieved in NTLEG GaN films by nanowire template as shown by cracks in nanowire 'legs' and lack of cracks/grooves. In contrast, in GaN grown directly on sapphire cracks propagate to the surface.

Vertically Aligned Nanowires – TEM Results and Growth Model

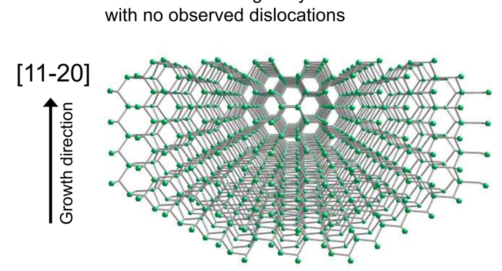


[11-20] oriented GaN nanowire *No catalyst tip*

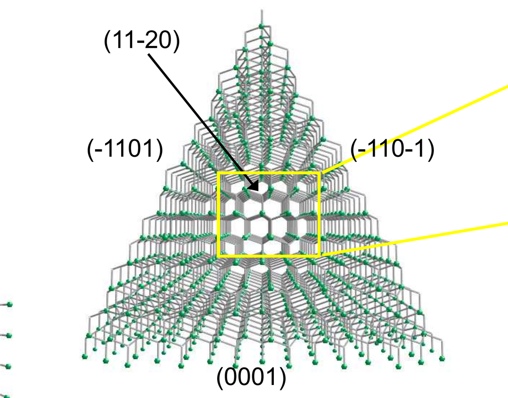
[11-20] oriented GaN nanowire *Ni catalyst tip*



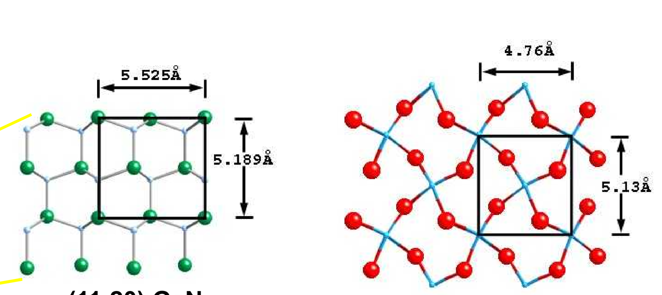
Nanowires are single-crystalline with no observed dislocations



[11-20] GaN Nanowire Side View



[11-20] GaN Nanowire Cross Section View Showing Side-Facet Planes



Nanowire growth direction same as (11-20) GaN film growth on r-plane sapphire – good crystallographic match explains vertical alignment.

- [0001]GaN||[-1101]sapp = 1.3% mismatch
- [-1100]GaN||[11-20]sapp = 15% mismatch

Wang, G. T., J. R. Creighton, A. Alec Talin, D. Werder, E. Lai, R. Anderson, I. Arslan. "Highly aligned growth and characterization of dense GaN nanowires on sapphire by metal-organic chemical vapor deposition." Nanotechnology 17 (2006) 5773-5780

Project Team

DOE NETL Project Manager: Brian Dotson

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