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Top-down III-Nitride nanowires

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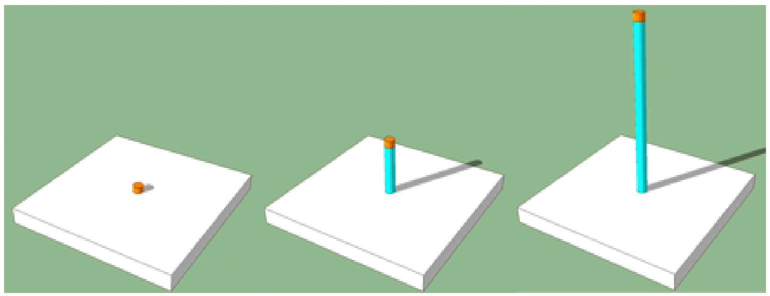
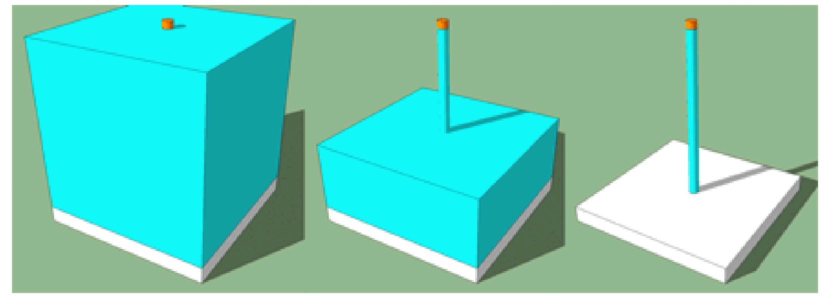
Outline

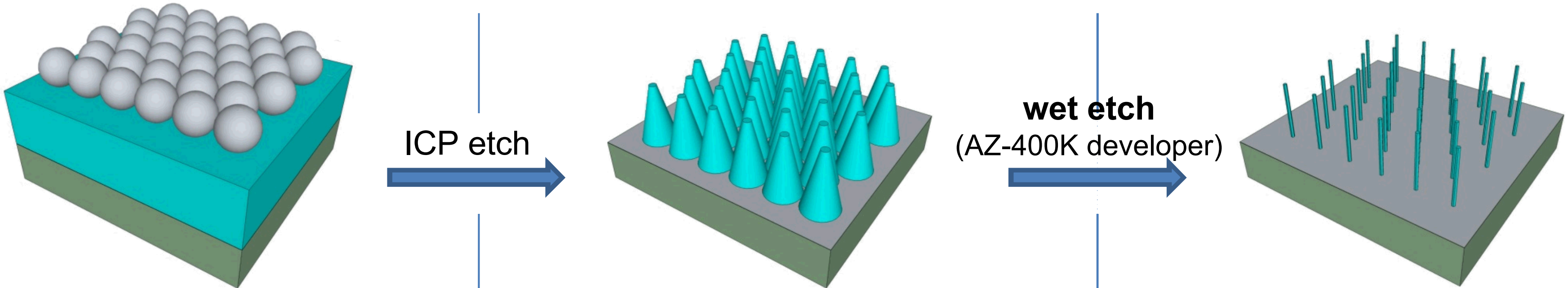
- Motivation: "Bottom up" vs "top down", pros and cons
- Experimental: 2-step etch technique
- Morphology: taperless, facet, dislocation, surface…
- Optical properties of GaN nanowires: PL, single mode lasing action
- Optical properties of InGaN/GaN LEDs nanowires: PL, IQE
- Summary

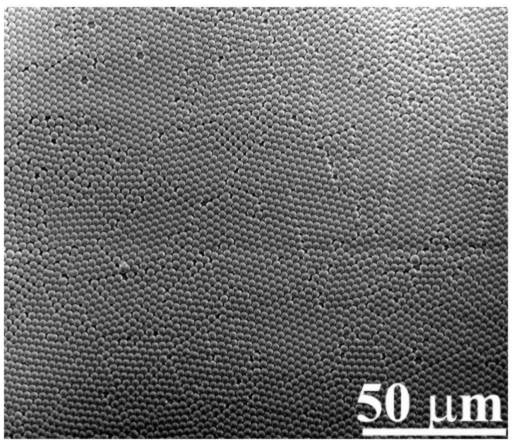
Motivation

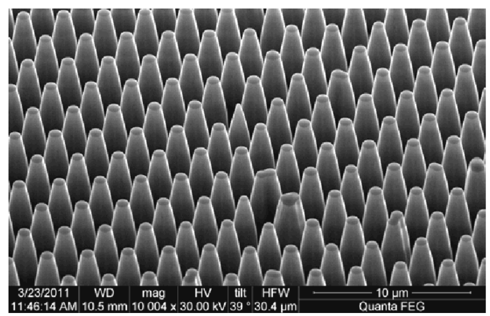
Bottom up (VLS or VS)	Top down
	

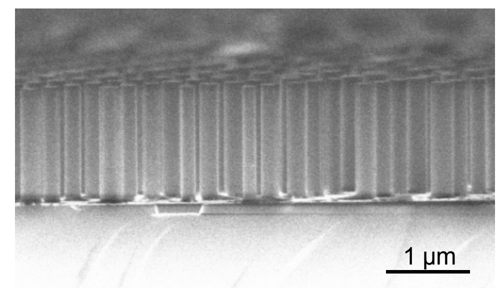
Less control over L and D ✗	Precise control over L and D ✔
Not uniform in L and D ✗	Very uniform in L and D ✔
Special growth conditions ✗ (catalyst, Low T, low V:III,...)	Normal growth conditions ✔ (no catalyst, high T, high V:III,...)
High point defect density ✗	Low point defect density ✔
Low IQE ✗	High IQE ✔
Low extended defect ✔	Low extended defect ✔

Top Down GaN nanorods









- Large area patterning
- Short range ordered
- Photolithography can be used

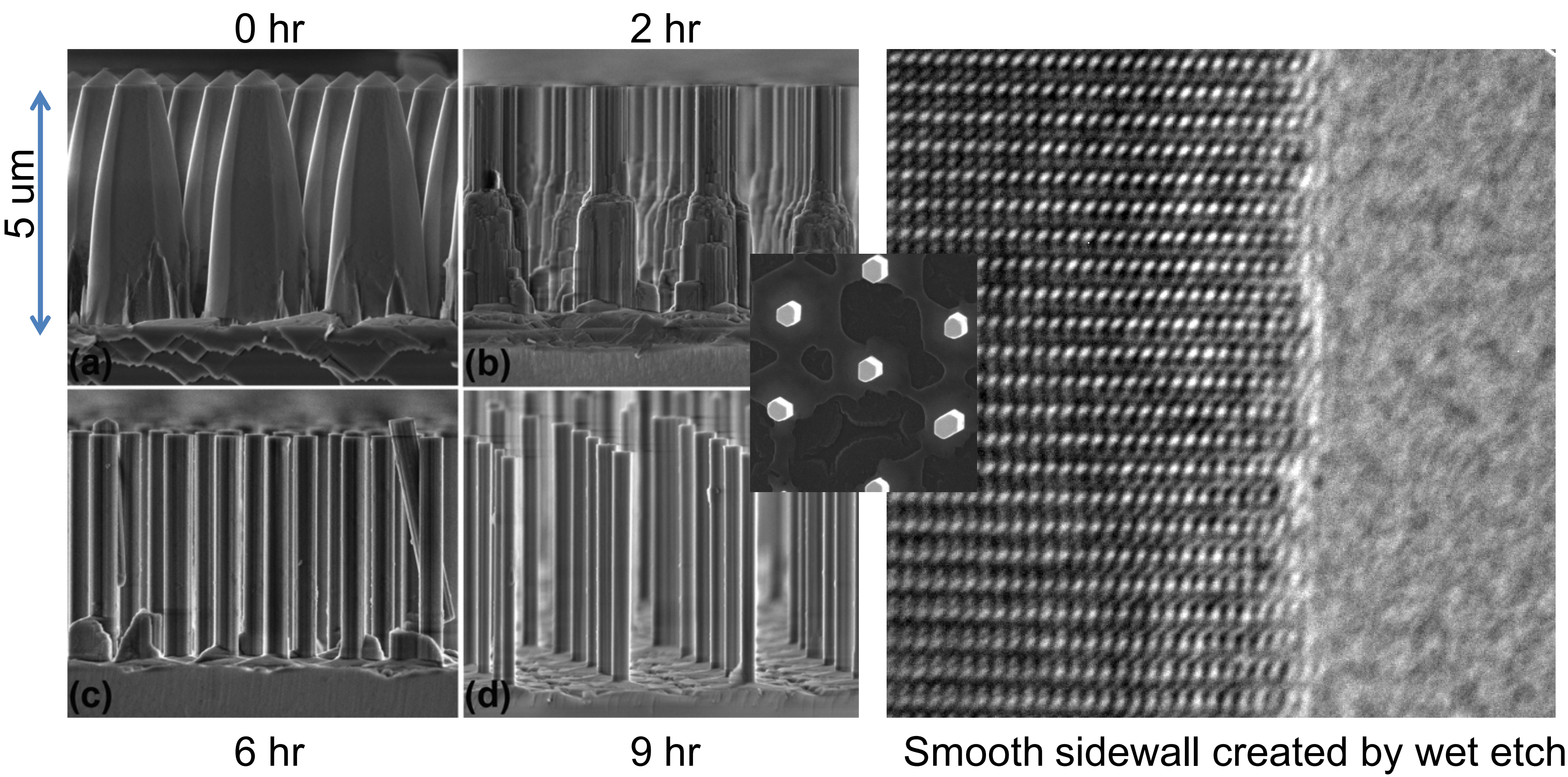
Q. Li, J. J. Figiel, G. T. Wang, Appl. Phys. Lett., **94**, 231105 (2009).

- Plasma etch causes sidewall damage
- Taper

C. Y. Wang et al., Opt. Expr. *16,* 10549–10556, 2008.

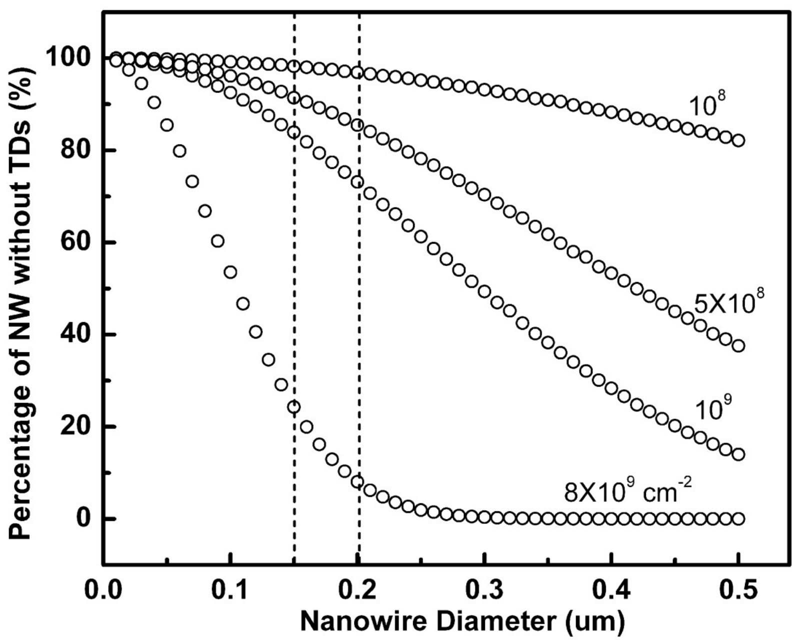
- Wet etch removes sidewall damage
- Removes taper
- Allow precise control on diameter
- Increase quality of the nanowire array

2-step ordered nanorod fabrication process

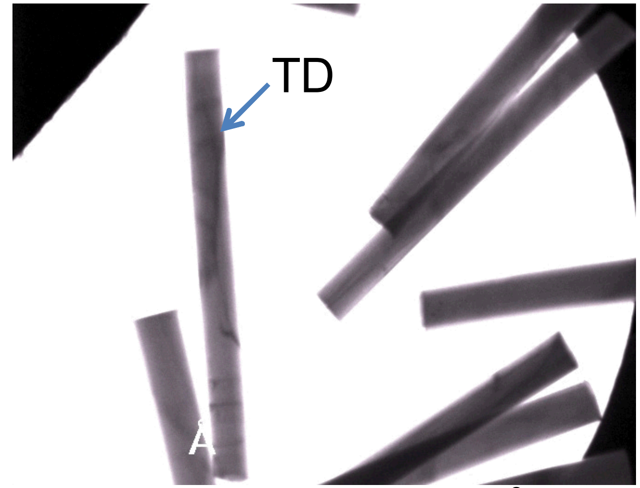


Nanorod threading dislocations as function of diameter

Monte Carlo simulation



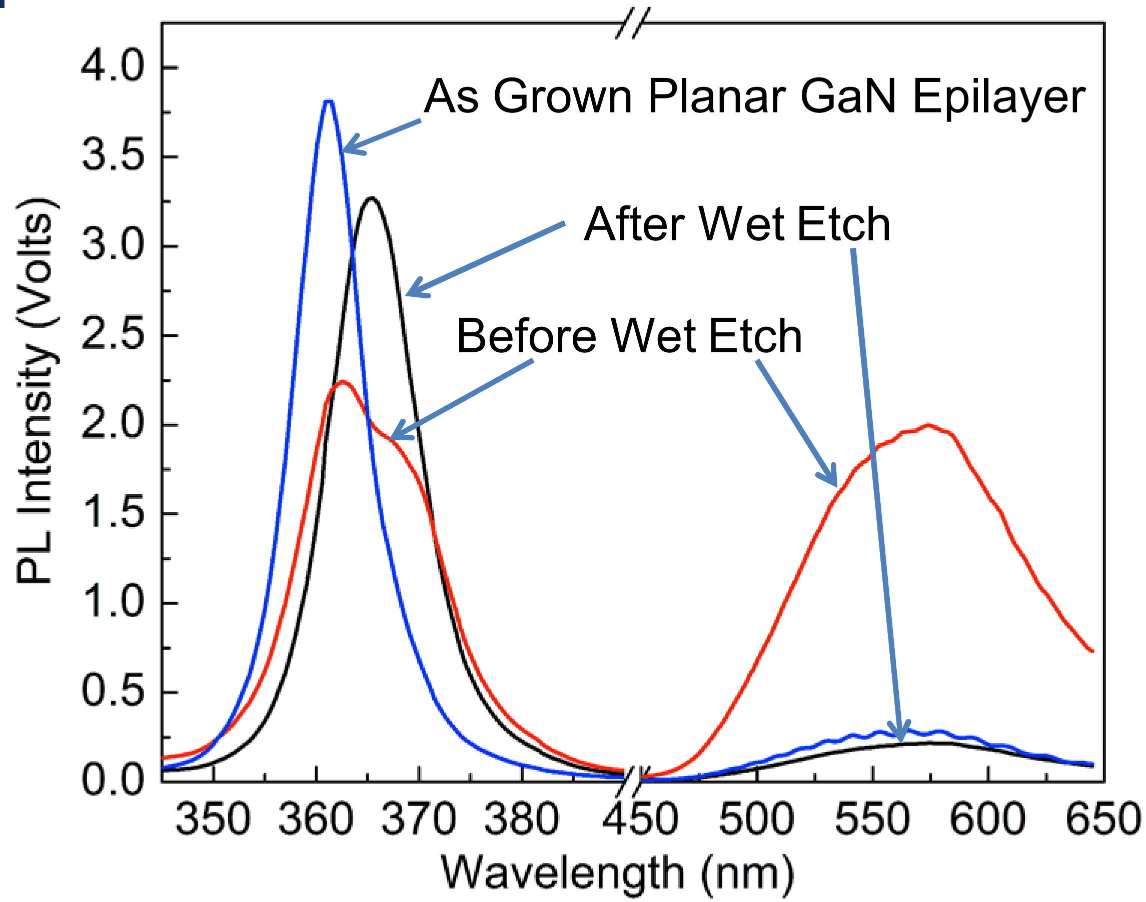
Bright-field TEM



Nanorods etched from ~5e8 cm^{-2} planar LED

- Etched nanorods inherit the dislocation density of the parent film
- However, as the diameter approaches zero, the *fraction* of nanorods with one or more dislocations also approaches zero! [# TDs per rod ~ (TDD)×($A_{cross-section}$)]
- *~94% of nanorods ~150 nm in diameter from TDD~5e8 cm^{-2} film dislocation free!*

Optical Properties of GaN Nanorods (Below Lasing Threshold)



- Plasma damage causes YL
- Wet etch removes plasma damage

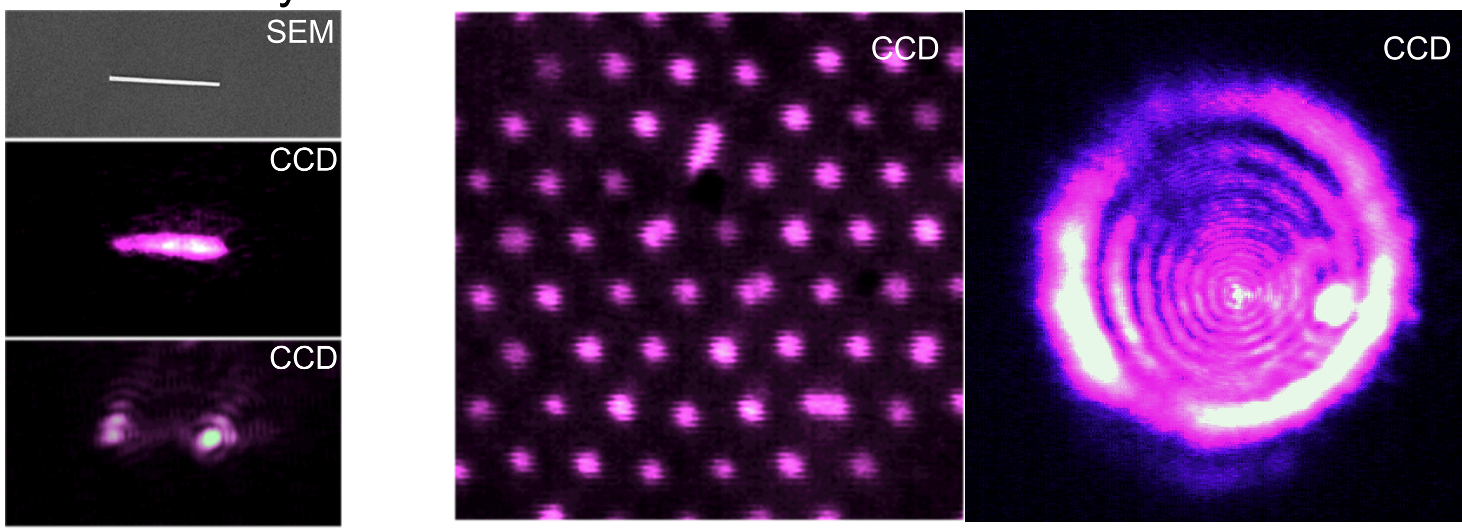
Lasing Action in GaN Nanorods (Optical Excitation)

Lateral Cavity

Vertical Cavity

Below Threshold

Above Threshold

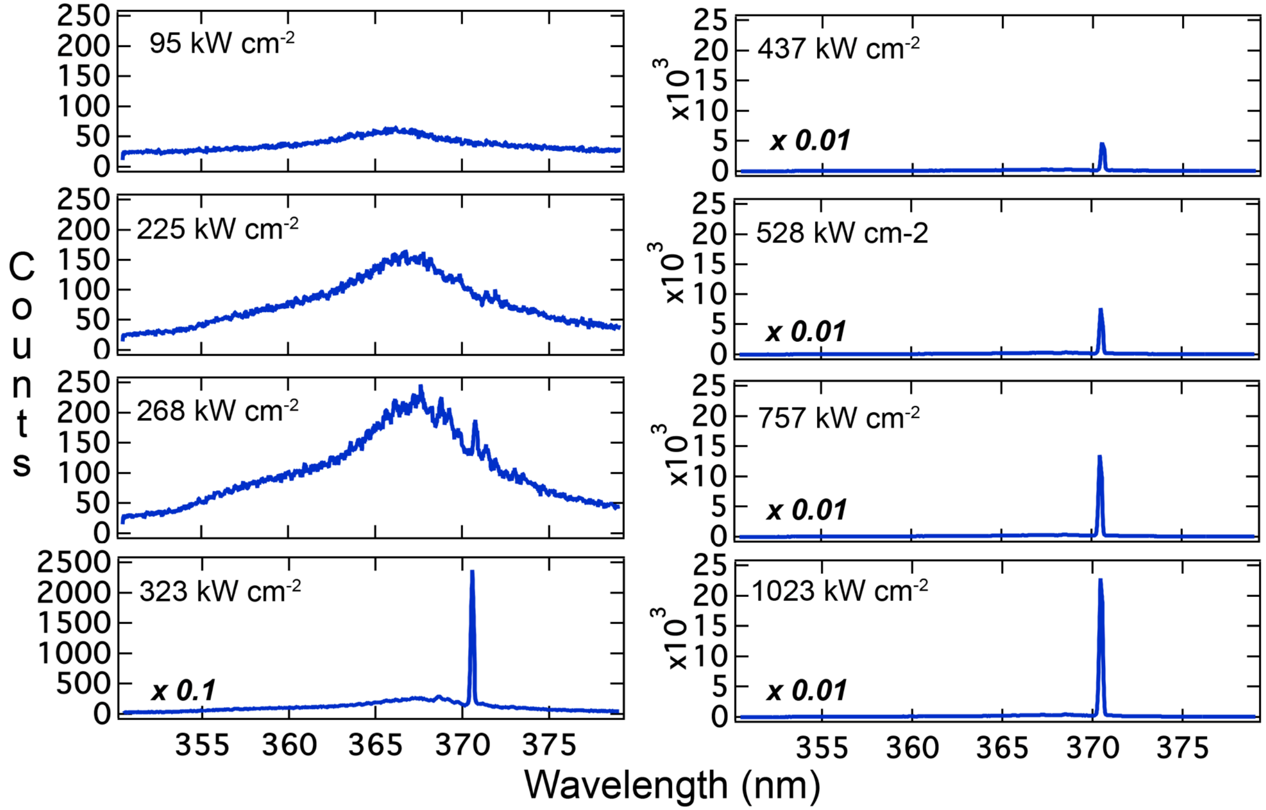


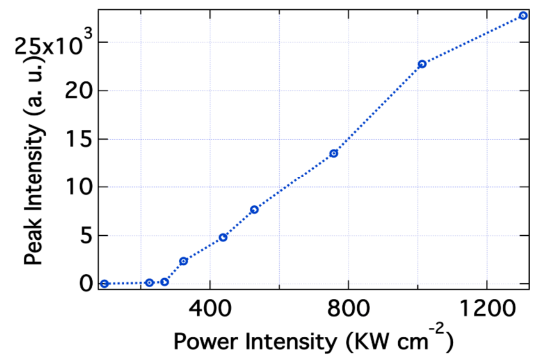
Below Threshold

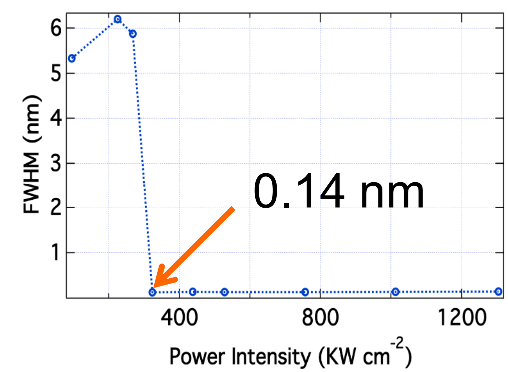
Above Threshold

- Fabry-perot cavity
- No need for cleavage
- Possible uniform vertical cavity laser array

Single Mode Lasing Action in GaN Nanorods (Optical Excitation)



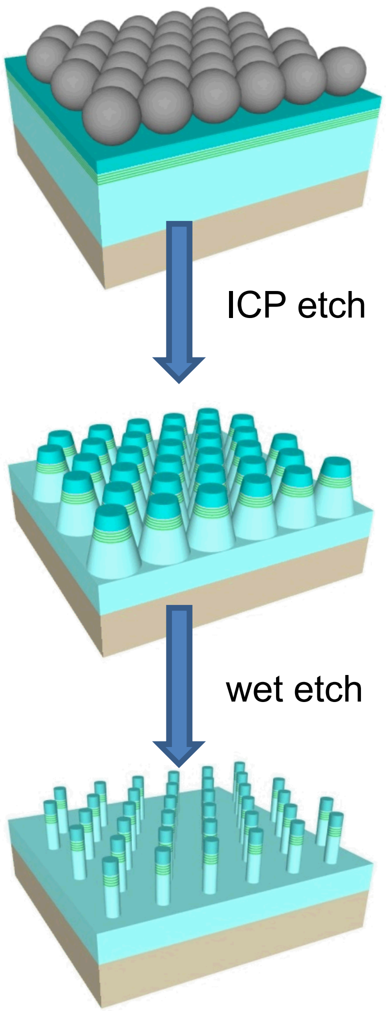


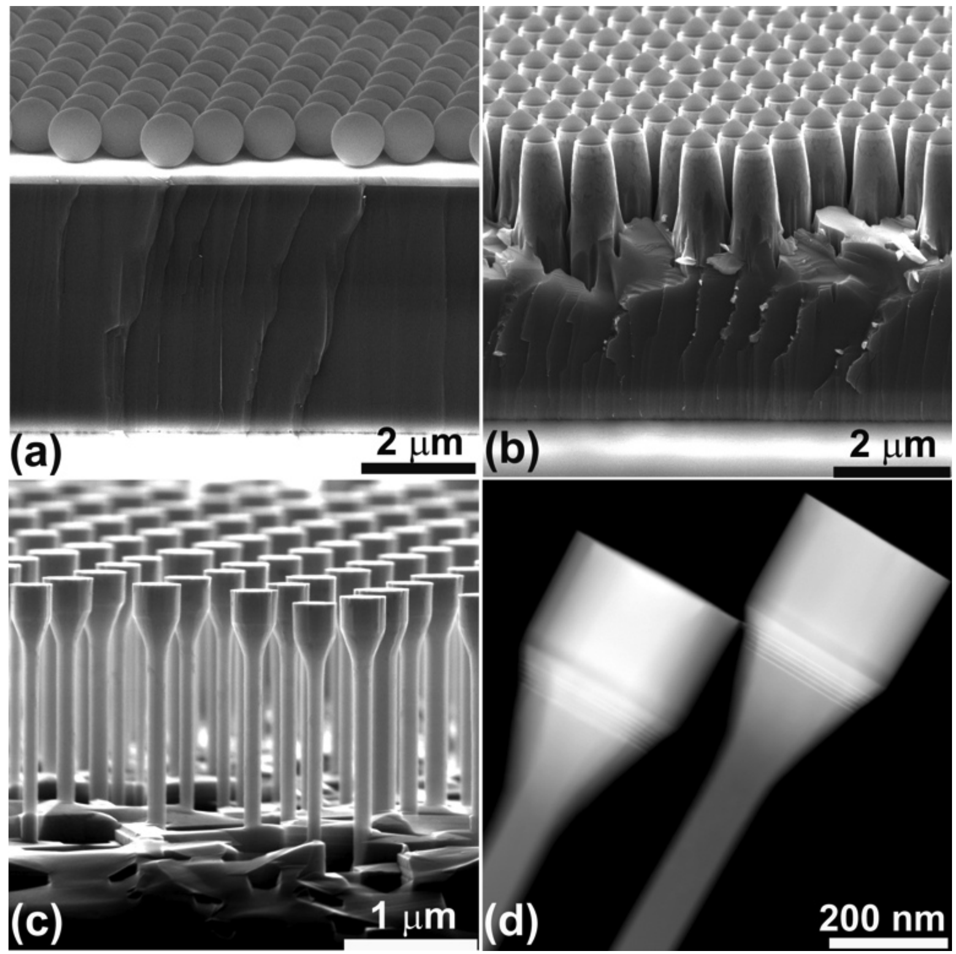


Low Threshold

1. Nanowire geometry: Φ 130 nm, L 4.6 um.
2. Single transverse mode.
3. Multiple longitudinal modes in the nanowire Fabry-Perot cavity.
4. Mode selection through gain spectrum overlapping with only one mode.

Axial GaN/InGaN LED Nanorods

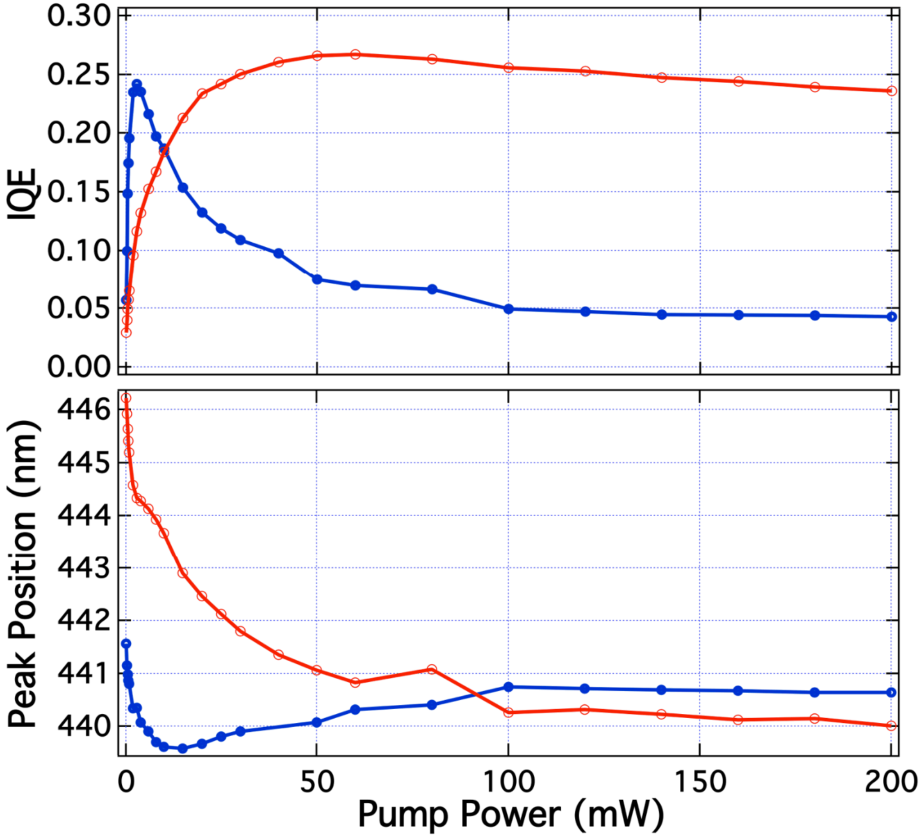




1, Flashlight shaped. 2, Nanowire array: ~95% TD free. 3, MQW:~75% strain relaxed

PL & IQE – Nanorod vs. planar InGaN/GaN LEDs

413 nm pump (InGaN selective)



1. Nanowire IQE peaks at low pump power
2. Maximum IQE similar
3. Sudden IQE drop for nanowire
4. Coincide with emission peak red shift
5. Possible heating in nanowire
6. Nanowire has 200X poorer thermal conduction
7. Planar sample peak blue shift (QCSE)

Summary

1. The anisotropic wet etch is key.
2. Precise control on geometry of nanowires.
3. Demonstrate single mode “top down” GaN nanowire laser.
4. Higher IQE possible.