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Nonpolar GaN/InGaN multi-quantum-well core-shell nanowire lasers

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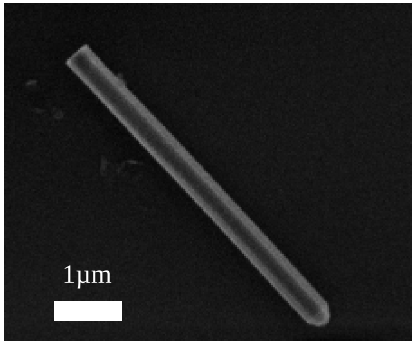

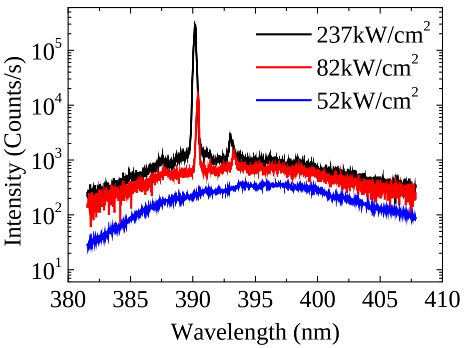

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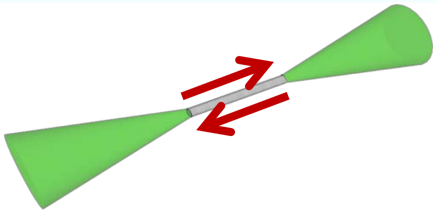
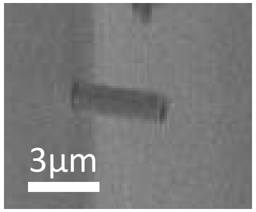
Outline

- Why non-polar III-nitride nanowire lasers?
- InGaN/GaN core-shell nanowire fabrication process
  - Top-down two-step etch process
- Experimental demonstration of lasing by optical pumping
  - Light-light curve
  - Lasing spectra
  - Confinement factor simulation
- Summary

Nanowire lasers – potential light sources for on-chip applications





- Nanowire lasers

  Optically or electrically pumped

  Semiconductor material – gain medium

  Cleaved facet – Fabry-perot cavity

- Advantages

  Strain relaxation

  – Reduce defect

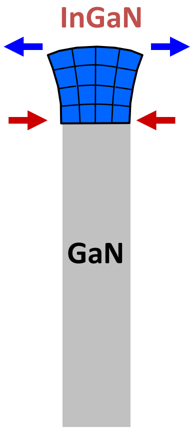
  Compact size

  – Low power requirement

  – Low threshold

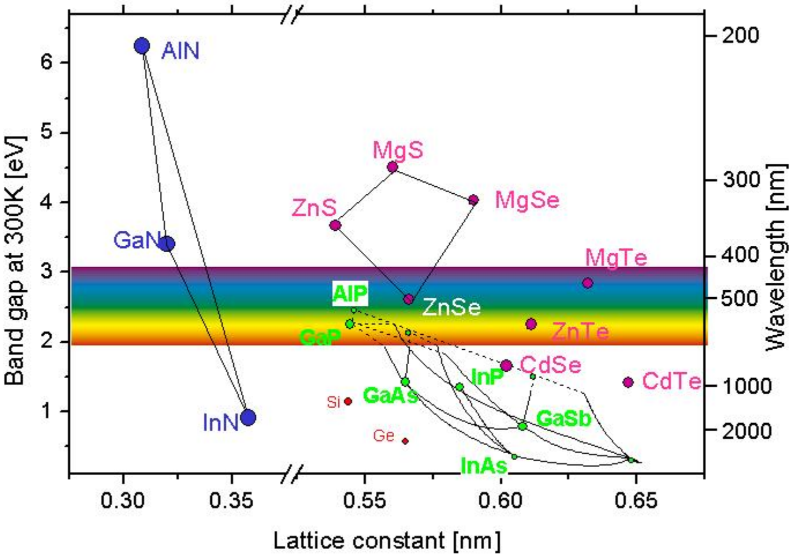
  – Desired for on-chip application

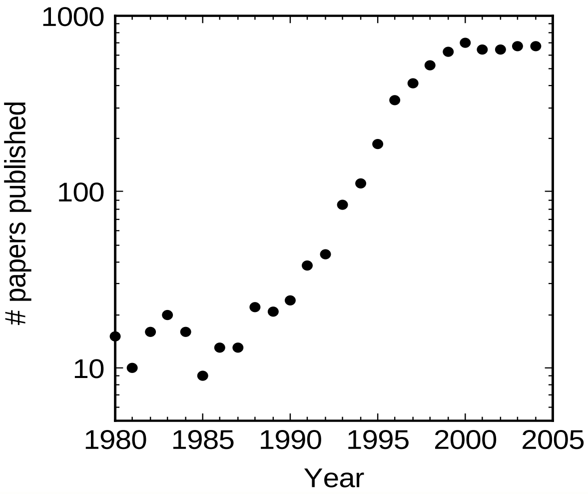
  – High speed communication

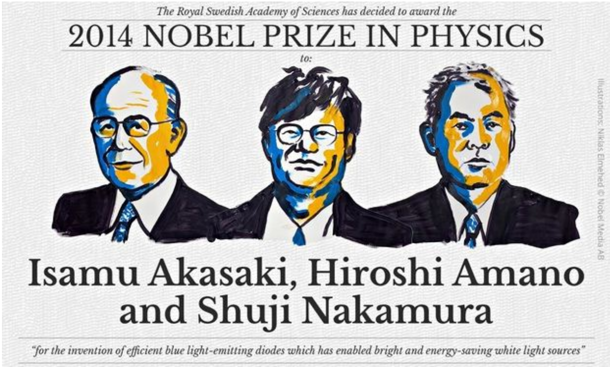


GaN and III-Nitride – important materials for optical devices

- Wide wavelength coverage
  - Solid-state-lighting (Visible)
  - Water purification (UV)
- Large exciton bonding energy
  - Low threshold lasing at room temperature
- Low surface state density
- High thermal and chemical stability



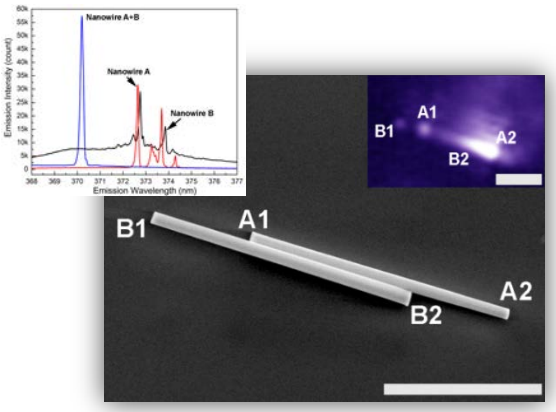




Prof. Ya-Hong Xie's group website. http://www.seas.ucla.edu/smrl/GaN.html

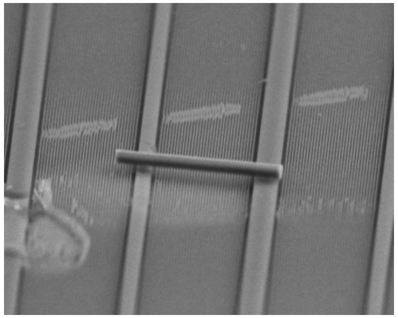
Previous research on top-down GaN nanowire lasers

Mode Control



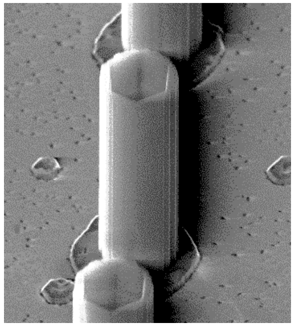
H. Xu et al., *Appl. Phys. Lett.* **101** 113106 (2012)
Q. Li et al., *Optics Express* **20** 17874 (2012)

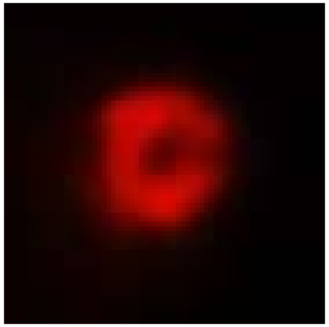
Distributed feedback NW lasers



J.B. Wright et al., *App. Phys. Lett.* **104** 041107 (2014)

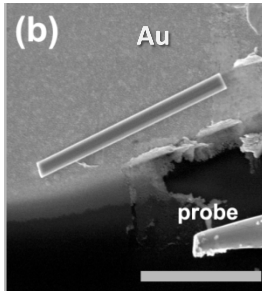
Beam shaping

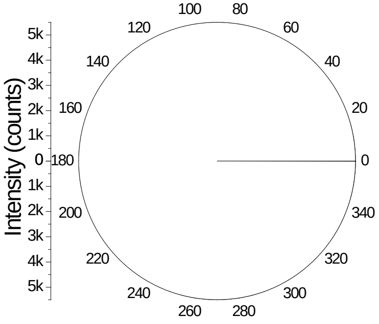




Changyi Li et al., under review

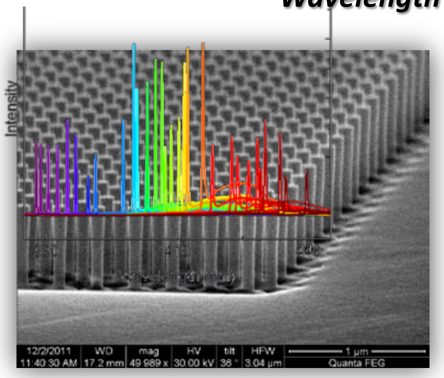
Polarization Control

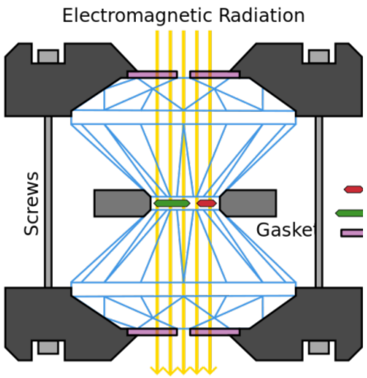




H. Xu et al., *Appl. Phys. Lett.* **101** 221114 (2012); H. Xu et al, Opt. Exp. (2014)

Wavelength Tuning Control

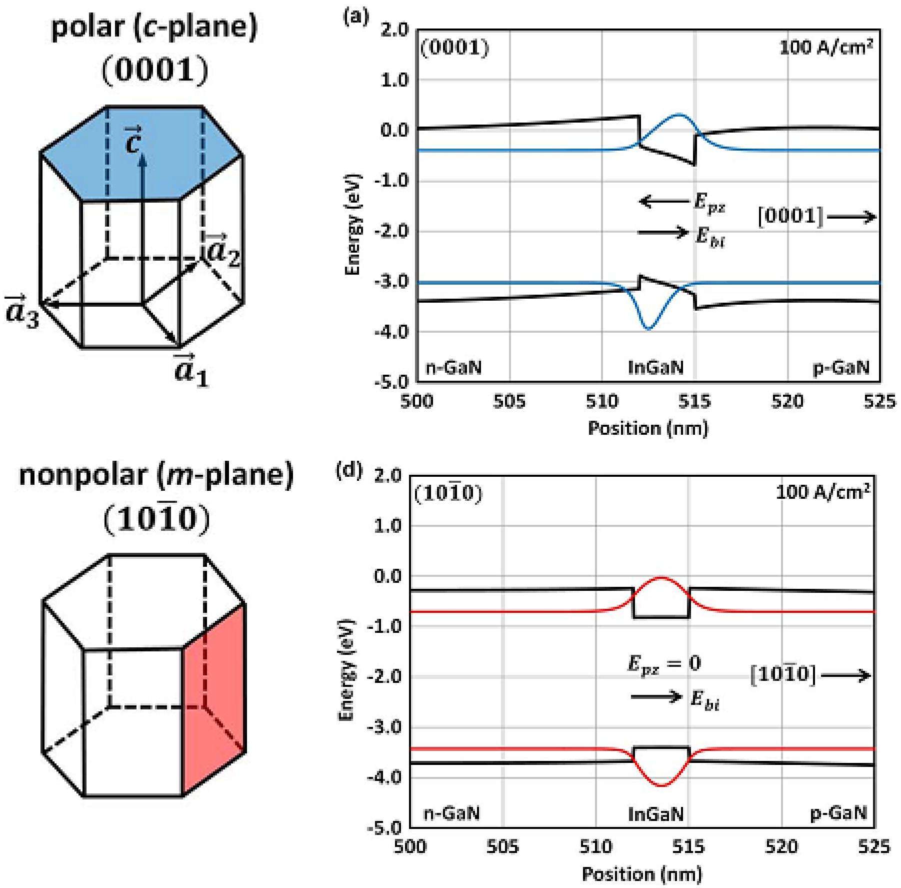




J.B. Wright et al., *Scientific Reports* 3, Article number: 2982 (2013) doi:10.1038/srep02982

Advantages of nonpolar core-shell nanowire laser

- Quantum-confined stark effect



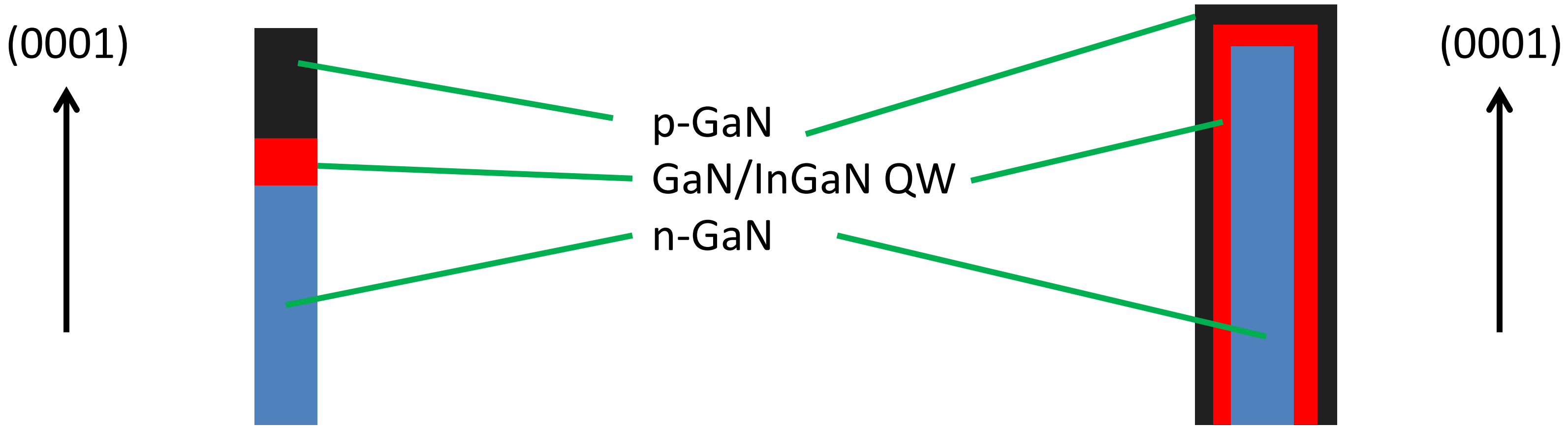
Feezell, Daniel F., et al. *Journal of Display Technology* 9.4 (2013): 190-198.

- Higher internal quantum efficiency
- No blue-shifting with increasing current

Advantages of nonpolar core-shell nanowire laser

- Larger active region, higher gain

L = 6 µm, R = 250nm, Thickness of QW = 20nm



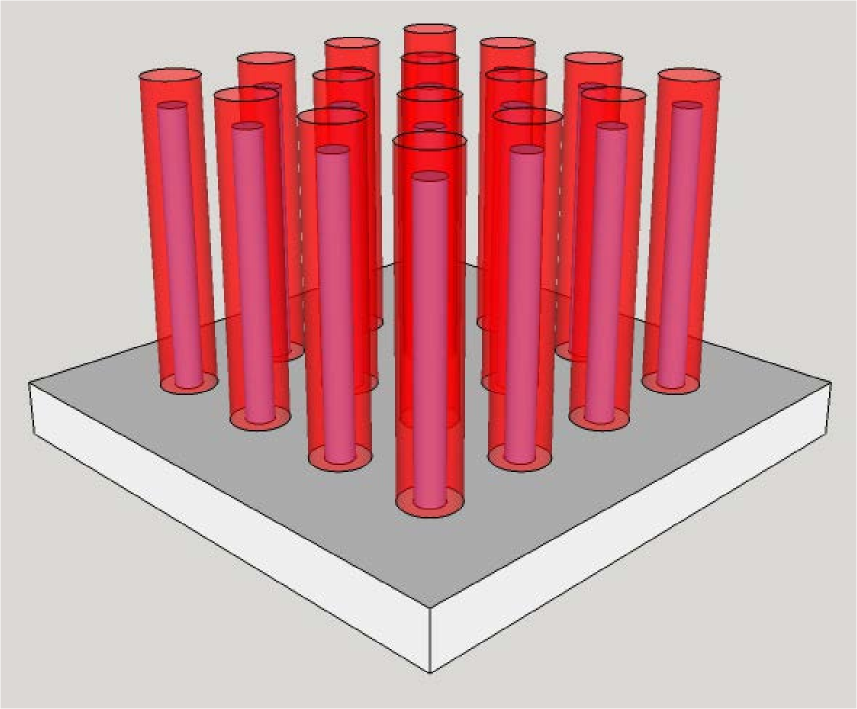
$V_{active} = 0.003925\ \mu m^3$

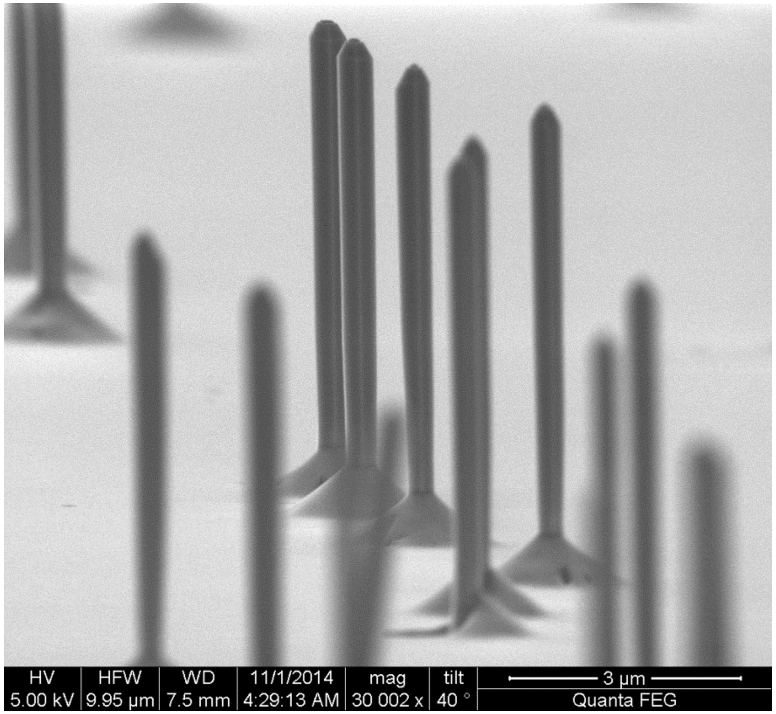
$V_{active} = 0.1884\ \mu m^3$

48 times larger active region

Fabrication – Top-down two-step etch process

Lithography patterned with PMMA lift-off

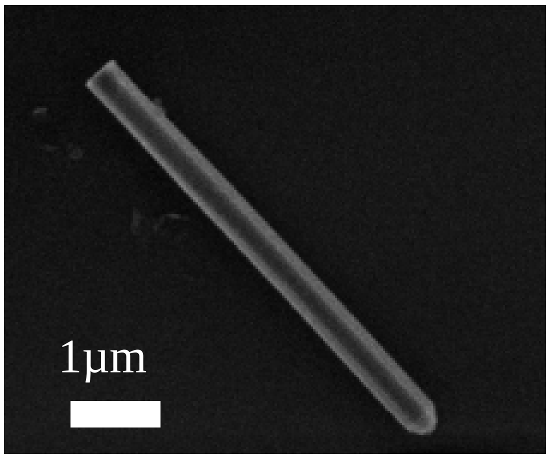


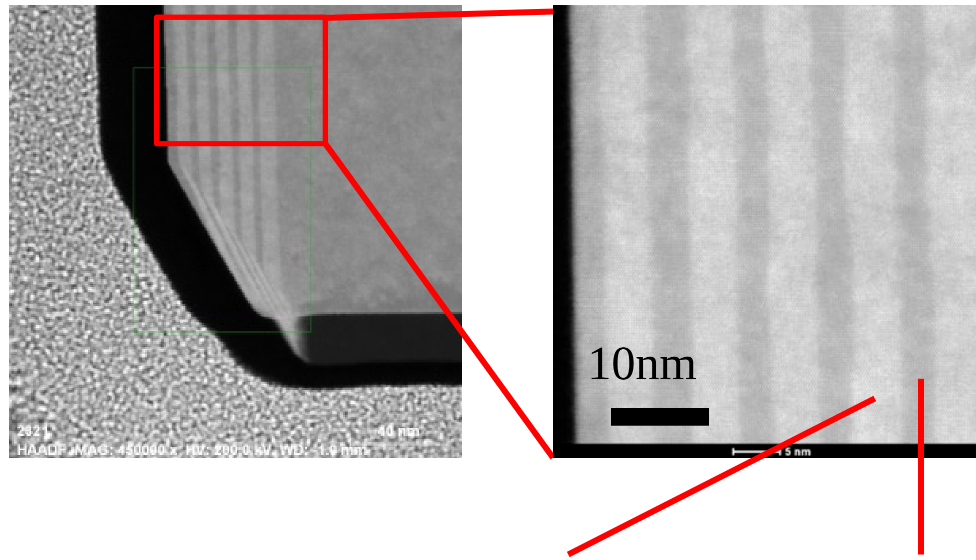


Details of the process, see

Li, Qiming, et al. *Optics express* 19.25 (2011): 25528-25534.
Li, Qiming, et al. *Optics express* 20.16 (2012): 17873-17879.
Wierer Jr, Jonathan J., et al. *Nanotechnology* 23.19 (2012): 194007.
Wang, George T., et al. *physica status solidi (a)* 211.4 (2014): 748-751.

Images of the fabricated core-shell nanowires

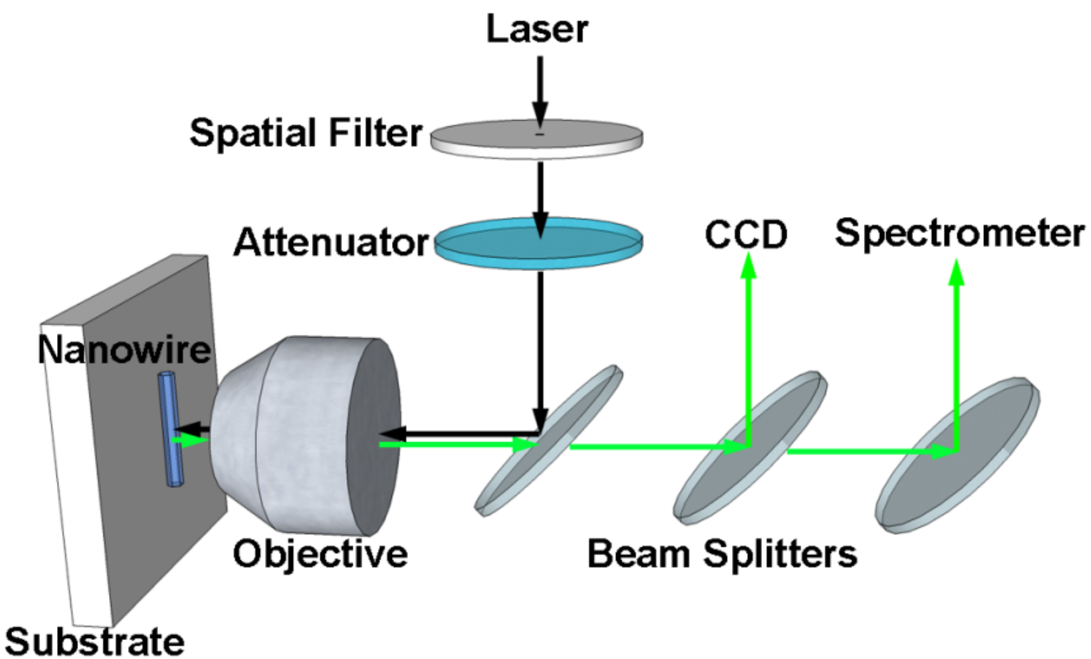




Length: ~5.6µm
Diameter: 400-600nm

Lasing?

Experimental Setup

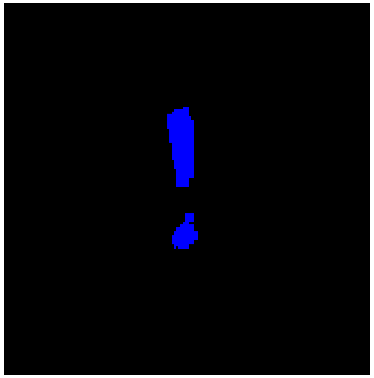


Pump laser:

Nd:YAG laser	@266nm
Pulse duration:	400 ps
Rep rate:	10 kHz
Duty cycle:	0.0004%
Tunable spot size:	>1µm

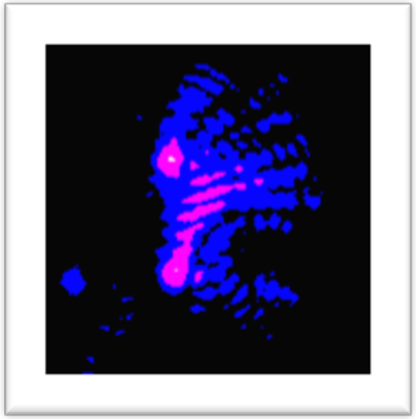
Microscopic CCD images

Lower pump power density



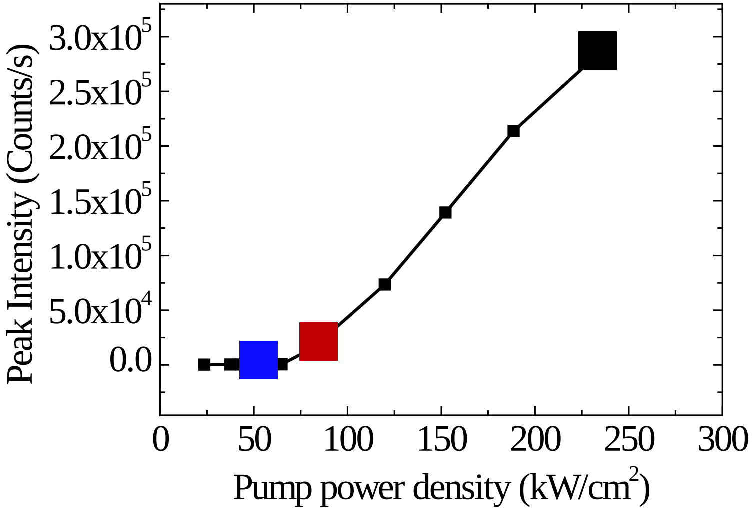
- Uniform intensity over the entire wire
  - Spontaneous emission
- No interference fringe
  - Incoherent emission

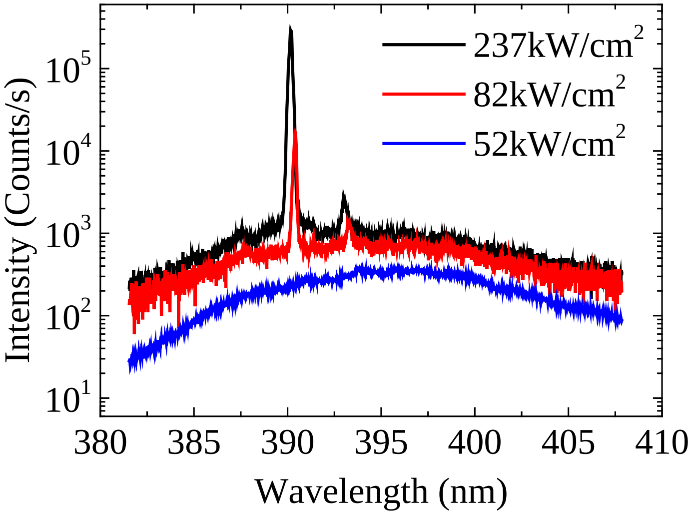
Higher pump power density



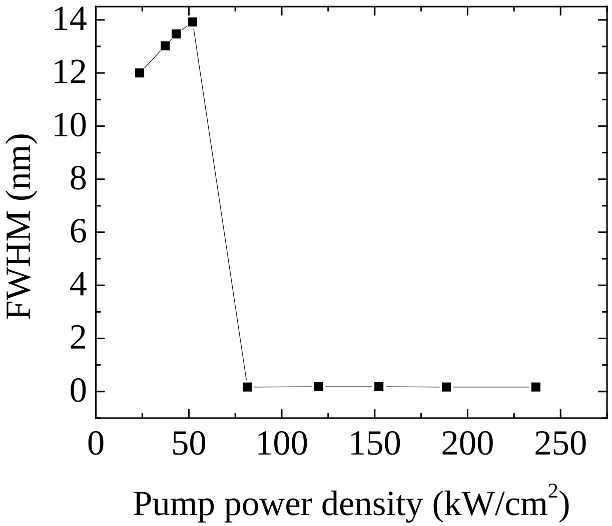
- High intensity at both ends
  - Strongly guided emission
- Interference fringe
  - Spatially coherent emission

Lasing Spectra and L-L Curve





Threshold pump density = 75kW/cm²
Lower than the threshold of GaN nanowire lasers in our group

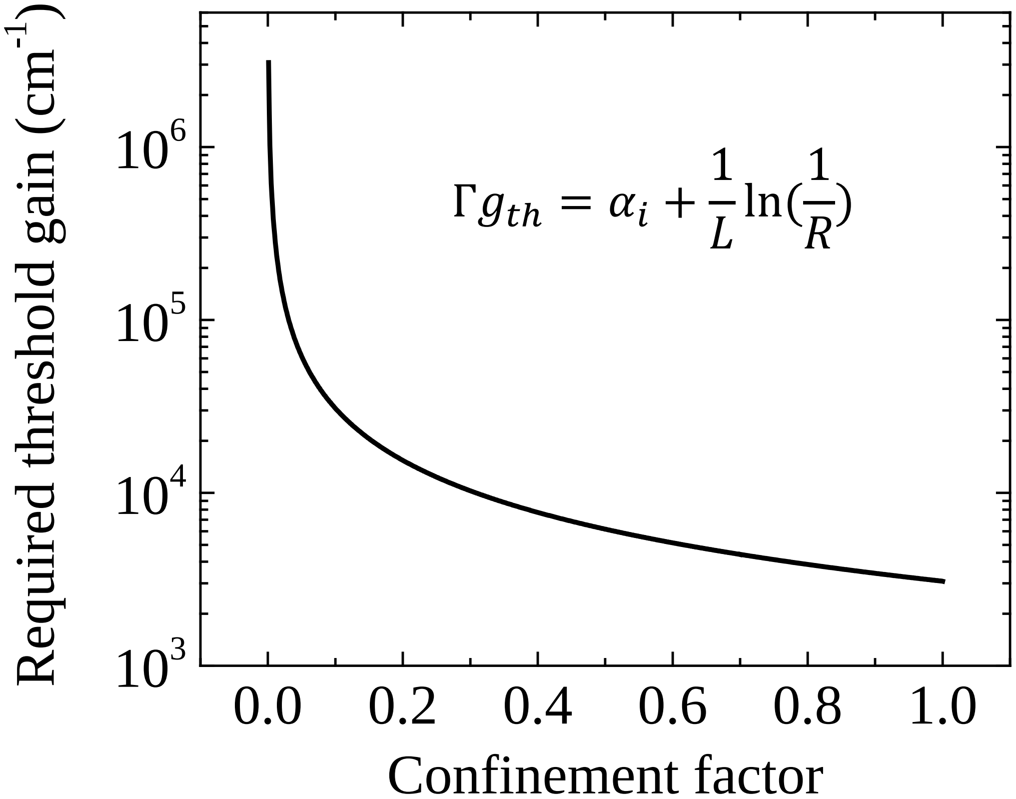


1st non-polar GaN/InGaN MQW core-shell nanowire laser

Simulation of transverse confinement factors

Assume:

- R = 0.16
- L = 6μm
- $\alpha_{\mathrm{i}} = 30cm^{-1}$



Control over **DIMENSIONS** of GaN/InGaN core-shell nanowire lasers

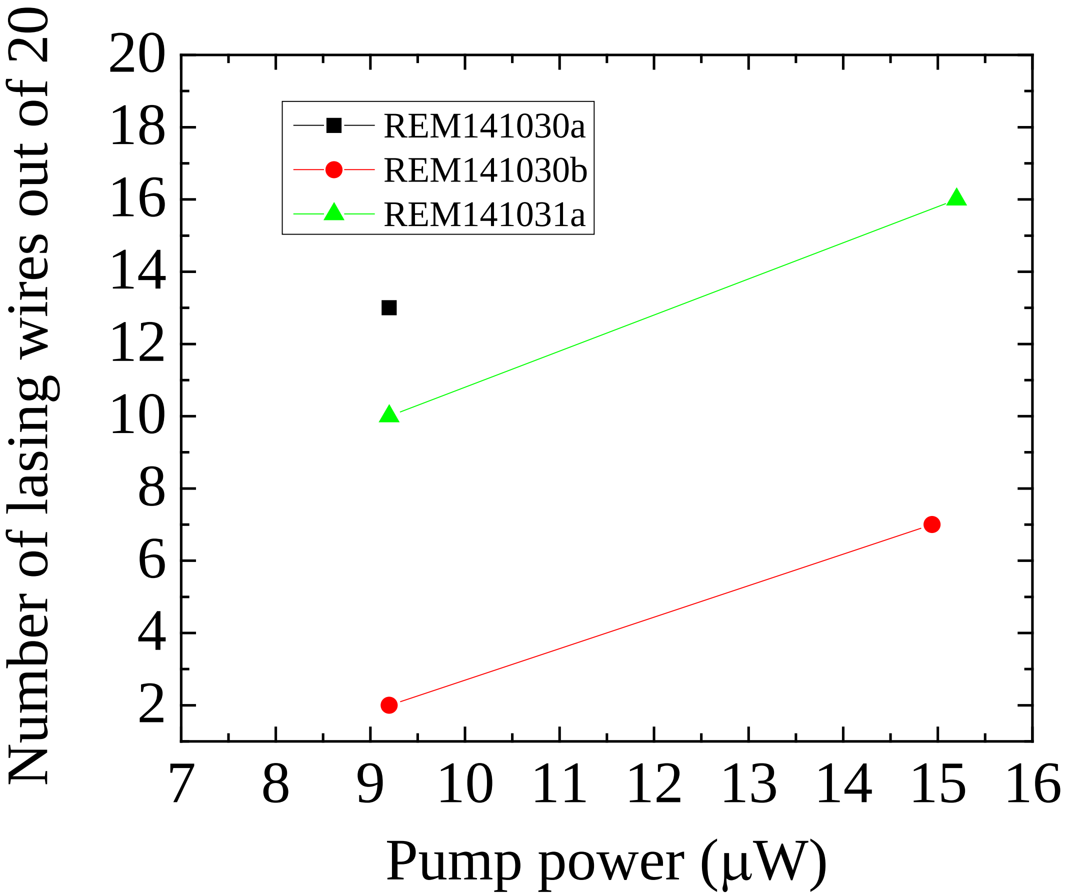
⬇

Optimize **CONFINEMENT FACTOR** of GaN/InGaN core-shell nanowire lasers

Lasing threshold study for different growth recipes

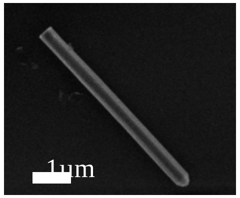
Difference in growth conditions:

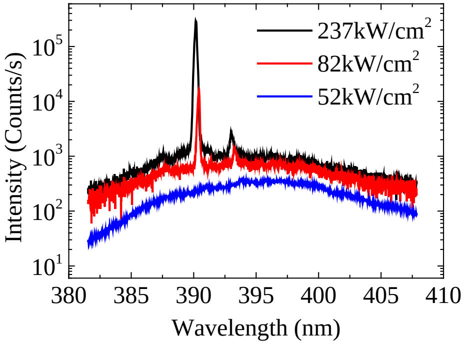
- InGaN QW thickness
- GaN barrier thickness
- # of QWs
- Electron blocking layer thickness
- p/p+ GaN layer thickness



Summary

- Fabricated nonpolar GaN/InGaN MQW core-shell nanowire
- First experimental demonstration of lasing from nonpolar GaN/InGaN MQW core-shell nanowire by optical pumping
- Simulated transverse confinement factor
- Future work
  - TEM characterization
  - Correlate measured lasing threshold with simulation





SW4F.6 **Wide and reversible tuning of an individual nanowire laser using hydrostatic pressure**

Sheng Liu

May 13 5:00 PM Executive Ballroom 210F

Thank you for your attention!

- Backup Materials

Simulation of transverse confinement factor

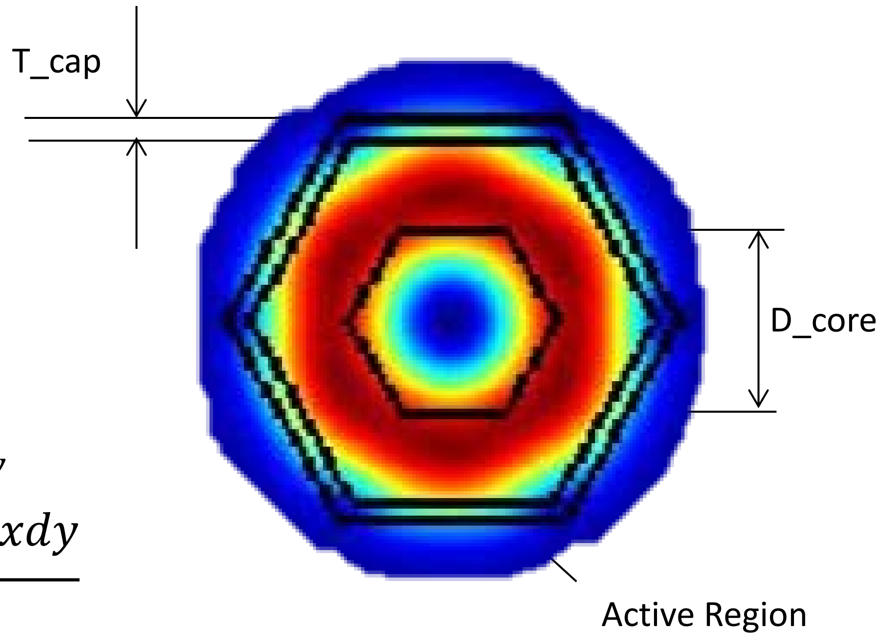
- Lumerical MODE solution

Define Nanowire Geometry

Solve for Eigen Modes

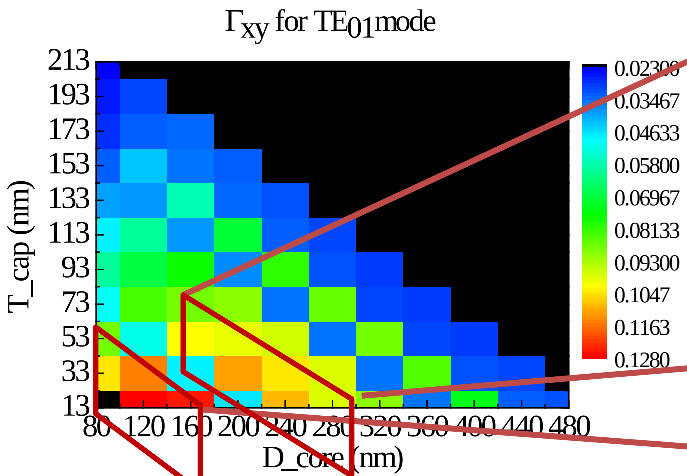
Calculate Confinement Factor Γ_{xy}

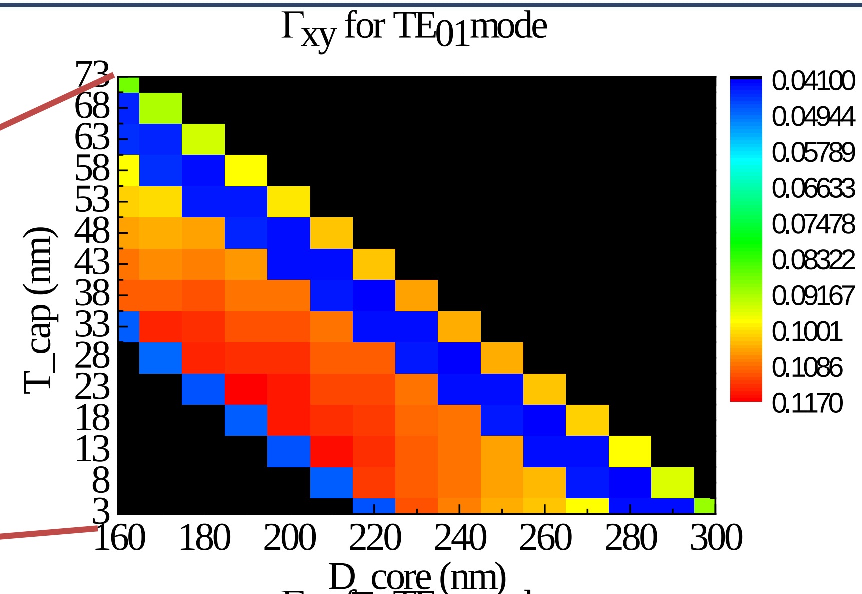
$$\Gamma_{xy} = \frac{\iint_{active\ region} |\langle S(x,y)\rangle| dxdy}{\iint_{-\infty}^{+\infty} |\langle S(x,y)\rangle| dxdy}$$

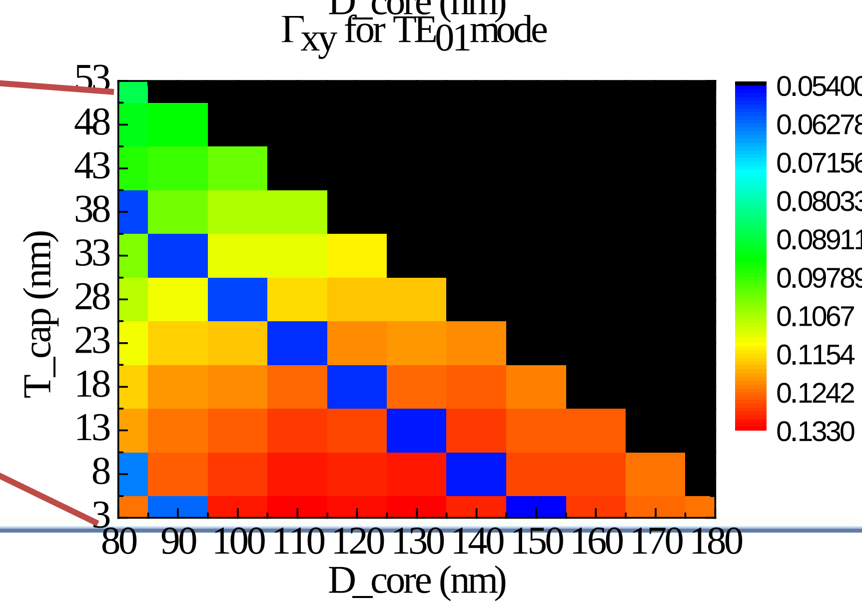


Simulation of transverse confinement factor

- TE_{01} Mode







Example:
T_cap=23nm
D_core=140nm
$\Gamma_{xy} = 0.12199$