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Top-down cross-section controlled III-nitride nanowire lasers

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Why cross-section control for nanowire lasers?

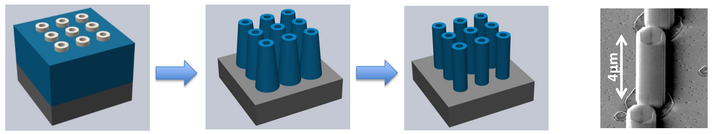
GaN nanotube lasers ► ► ► Beam shaping
- Annular-shaped emission
  - Atom trapping
  - Stimulated emission depletion microscopy

Rectangular GaN nanowire lasers ► ► ► Linear polarization
- Intrinsic control (no additional environment requirement)
- Beneficial for polarization-sensitive on-chip components

Nonpolar core-shell nanowire lasers ► ► ► UV-visible lasers
- No quantum-confined stark effect
- High material gain and low lasing threshold
- Potential confinement factor engineering
- Compatible architecture for electrical injection

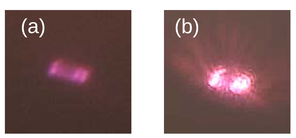
Structure 1: Annular-shaped emission from GaN nanotube lasers

Cross-sectional shape control enables beam shaping

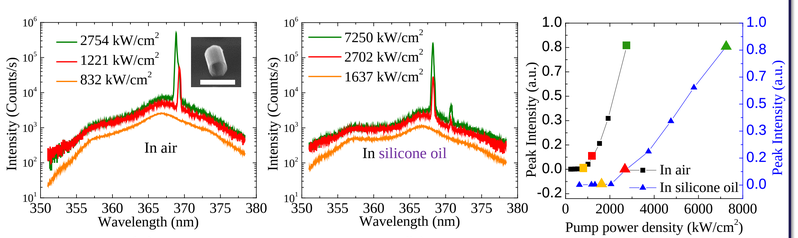


(a) (b) (c) (d)

Top-down two-step etch process: **(a)** Ni ring patterns were deposited on a planar III-nitride substrate and then transferred into the substrate by **(b)** ICP dry etch and **(c)** KOH (AZ400K) wet etch. **(d)** An SEM image of a GaN nanotube (Length: 4 μm; Outer diameter: 1.3 μm; Shell thickness: 150 nm)

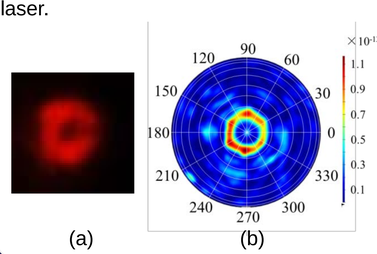


CCD images of the GaN nanotube laser excited **(c)** below and **(d)** above lasing threshold



(a) (b) (c)

Spectra of the emission from a GaN nanotube laser **(a)** in air and **(b)** in silicone oil, showing potential in nano-fluidic applications. **(c)** L-L curves of the GaN nanotube laser.

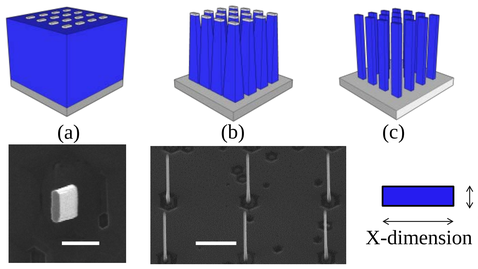


(a) (b)

(a) CCD image of the end-facet emission of the GaN nanotube laser. **(b)** Simulation results of the far-field intensity of the GaN nanotube laser in spherical coordinate system. The annular-shaped emission can be potentially used for atom trapping or STED microscopy

Structure 2: Intrinsic linear polarization from rectangular GaN nanowire lasers

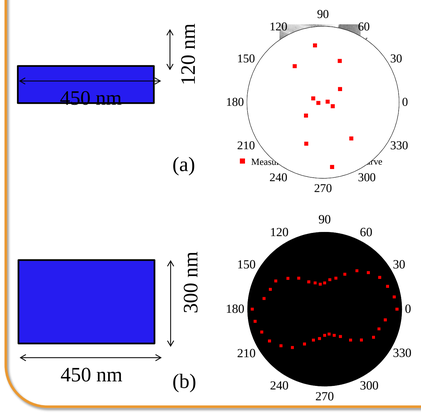
Cross-sectional shape control enables intrinsic polarization control



Top-down two-step etch process: **(a)** E-beam litho. **(b)** ICP dry etch. **(c)** KOH (AZ400K) wet etch. **(d)** Plan-view and **(e)** 45º view SEM images of a rectangular GaN nanowire laser. Scale bar: 2.5 μm **(f)** Diagram shows the long x- and short y-axes.

PL Spectra of a rectangular GaN nanowire laser. The narrow-band emission indicates the onset of lasing

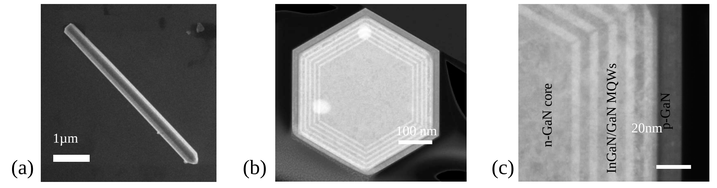
Simulated transverse confinement factors of transverse modes of rectangular GaN nanowire lasers. **The modes polarized along the y-direction have higher Γ_{xy} when the y-dimension is ~120 nm.**



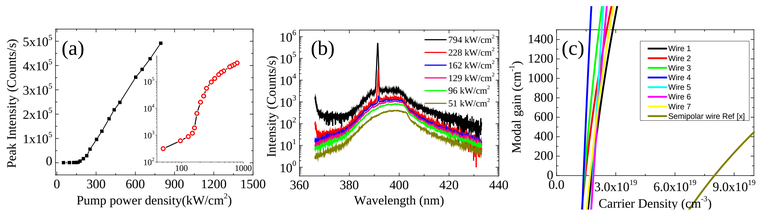
(a) Intrinsic, linearly polarized emission with an extinction ratio of 14:1 was observed from the end-facet emission of nanowire A (x-dimension: 450 nm, y-dimension: 120 nm). Inset: the SEM image of the GaN nanowire. The major axis of the linearly polarized emission is along the y-direction of the rectangular nanowire laser.**(b)** Elliptically polarized emission from nanowire B (x-dimension: 450 nm, y-dimension: 300 nm).

Structure 3: Single non-polar p-i-n InGaN/GaN multi-quantum-well nanowire lasers

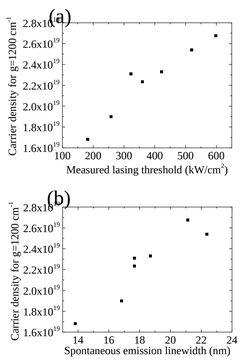
Potential UV-visible electrically injected single nanowire lasers



(a) SEM image & **(b & c)** High resolution cross-sectional scanning TEM images of a core-shell nanowire. 5 quantum-wells (QWs) are re-grown on the nonpolar *m*-planes of a n-GaN nanowire core fabricated by the top-down two-step process.



(a) L-L curve of a core-shell nanowire in linear and log scales. The "kink" in the curve indicates the lasing threshold (180 kW/cm²). **(b)** PL spectra of the core-shell nanowire lasers. Narrow-band lasing peaks were observed above the lasing threshold. **(c)** Gain curves of 7 nonpolar core-shell nanowire lasers and the previously reported semipolar core-shell nanowire laser. **The nonpolar core-shell lasers exhibit lower transparency carrier densities & higher differential gains.**



(a) Core-shell nanowires that require lower carrier densities for $g = 1200cm^{-1}$ indicate higher gain quality and correspond to lower measured lasing thresholds. **(b)** Higher gain quality corresponds to narrower spontaneous emission linewidth. The results imply that the variation of the lasing threshold for the 7 core-shell nanowire lasers is because of the nonuniform material gain, which comes from the inhomogeneous regrowth

Conclusions

- Annular-shaped emission from GaN nanotube lasers potentially for nanofluidic and atom trapping and STED microscopy applications.
- Intrinsic linearly polarized emission from rectangular GaN nanowire lasers potentially for on-chip polarization-sensitive applications.
- Single nonpolar InGaN/GaN MQW core-shell nanowire lasers with low threshold, compatible p-i-n architecture for electrical injection

Publications

1. Q. Li, et al. *Opt. Express* **20**, 17873 (2012).
2. Q. Li, et al. *Opt. Express* 19, 25528 (2011).
3. C. Li, et al. *ACS Photonics* 2, 1025 (2015).
4. C. Li, et al. *Nanoscale* **8,** 5682-5687 (2016).

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