Lasing from III-N Nanowires

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Why Lasers for Solid State Lighting?

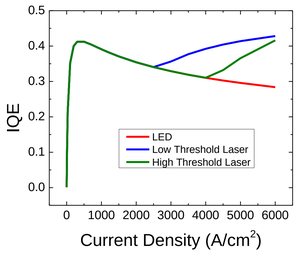
- Stimulated emission clamps the carrier density
- Lasers offer an avenue for bypassing efficiency droop at high current densities
- There are novel existence proofs for ultra-efficient lasers (>70%) at other (IR) wavelengths

Why Nanowires as Lasers?

- Relaxed strain opening up growth substrate possibilities
- Large optical confinement
- Can accommodate a wider range of alloy compositions
- Typically free of threading dislocations

Importance of Single-Mode

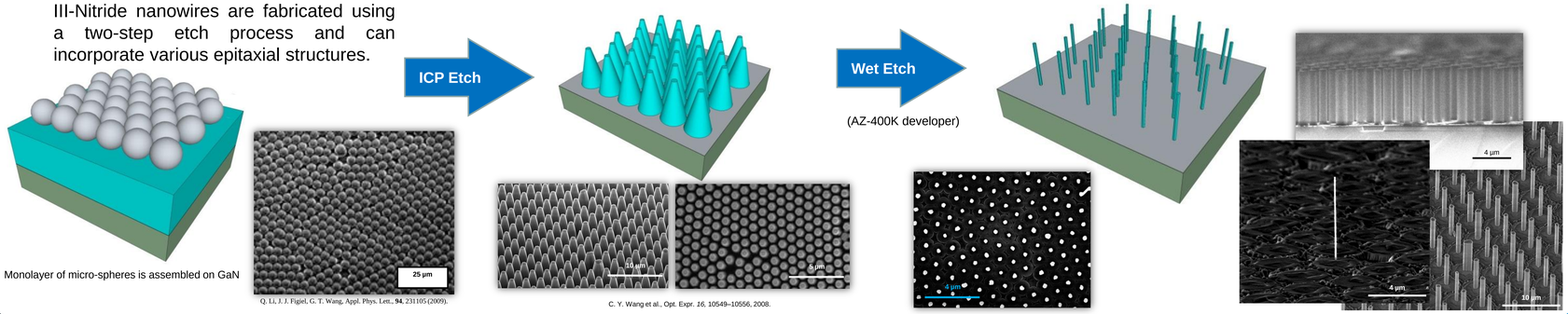
The benefits of single-mode are low threshold and low intensity noise. When using stimulated emission to work around the efficiency droop of III-N emitters it is necessary to have a low threshold. Single-mode lasers have a lower threshold compared to multimode emitters.



In a device with feedback the onset of stimulated emission overcomes the efficiency droop of the LED. Having a lower threshold means the droop is minimized at lower current densities.

Fabrication of GaN Nanowires

III-Nitride nanowires are fabricated using a two-step etch process and can incorporate various epitaxial structures.

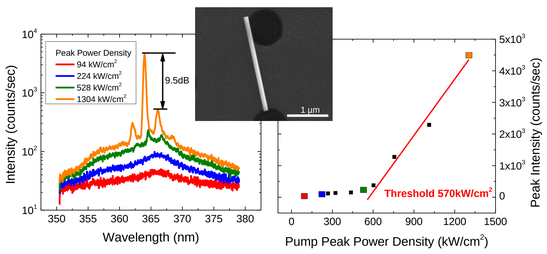


Q. Li, J. J. Figiel, G. T. Wang, Appl. Phys. Lett., **94**, 231105 (2009).

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

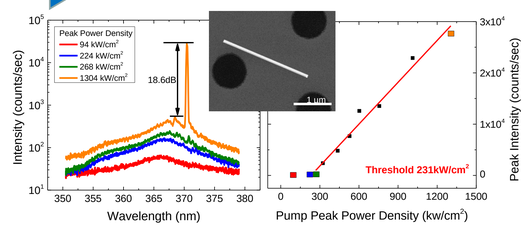
Multimode Lasing

Spectra from a 200nm x 5μm GaN nanowire with various pump intensities. This laser has a high threshold and low side mode suppression.

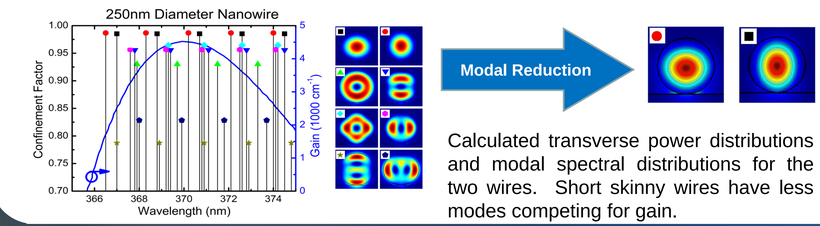


Dimension Reduction

Single-Mode Lasing



By reducing the width of the wire the number of competing modes is reduced. A 130nm x 5μm wire exhibits single mode lasing with a reduced threshold and high side mode suppression.



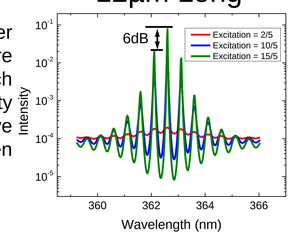
Calculated transverse power distributions and modal spectral distributions for the two wires. Short skinny wires have less modes competing for gain.

Modeled modal spectral distribution and gain vs. wavelength.

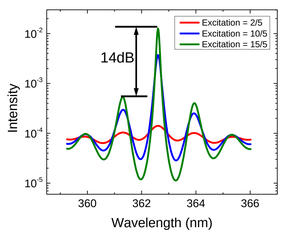
Mode Competition

12μm Long

Using a multimode laser theory, calculations are used to determine which of the passive-cavity eigenmodes will be above lasing threshold for given experimental conditions.

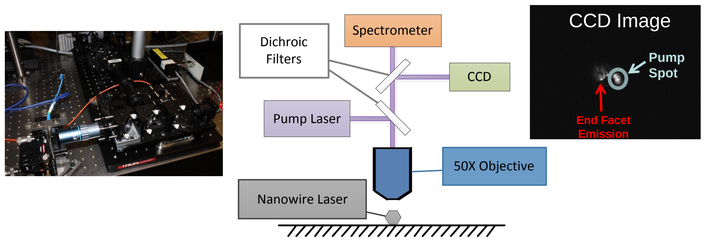


4μm Long



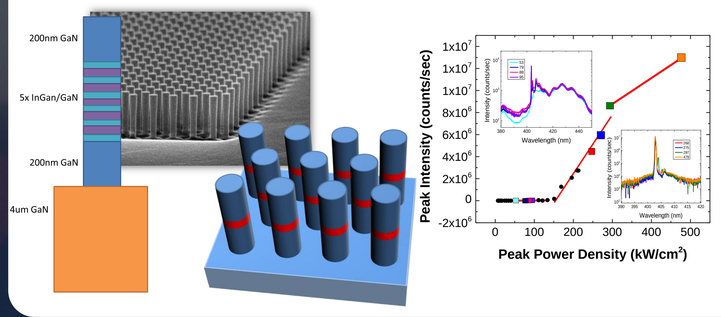
Modeling shows that by reducing the dimensionality of the wire we can reduce the number of competing modes.

Characterization of III-N Nanowires



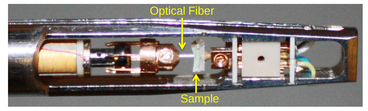
GaN nanowires lying on a substrate are optically excited through a 50x objective by a 266nm laser whose power is trimmed by a series of neutral density filters. Emission from the nanowire is collected through the same objective and is characterized by a spectrometer.

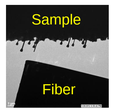
Photonic Crystals with InGaN Quantum Wells



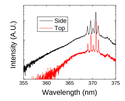
Future Efforts

In-Situ TEM PL

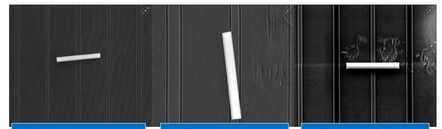




Light can be collected by a fiber from the nanowire facets.



Distributed Feedback with Single GaN Nanowires



Wires are placed on gratings with random orientations.

The wire is then rotated to minimize optical feedback.

The wire is finally rotated to maximize optical feedback.

Distributed feedback can:

- Reduce laser threshold by adding additional reflectivity
- Aid in frequency selection

This work was performed, in part, at the Center for Integrated Nanotechnologies, a U.S. Department of Energy, Office of Basic Energy Sciences user facility.
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