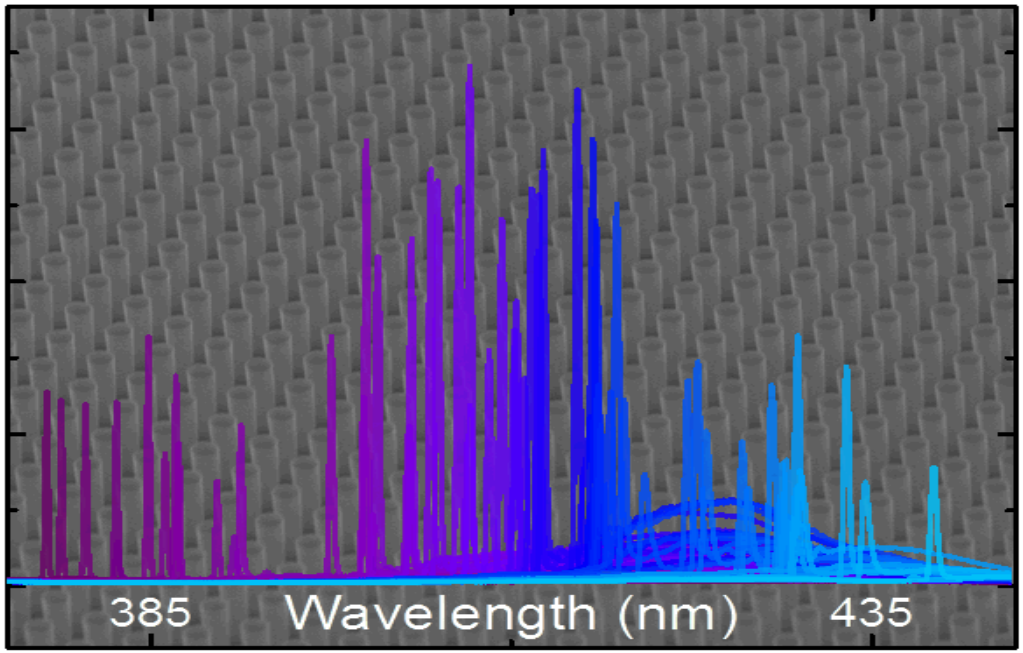
Tunable Blue-Violet III-Nitride Nanowire Photonic Crystal Lasers

SAND2013-0823C

Jeremy B. Wright, Sheng Liu, George T. Wang, Qiming Li, Daniel D. Koleske, Ping Lu, Huiwen Xu, Luke Lester, Ting S. Luk, Igal Brener, Ganapathi S. Subramania



Outline

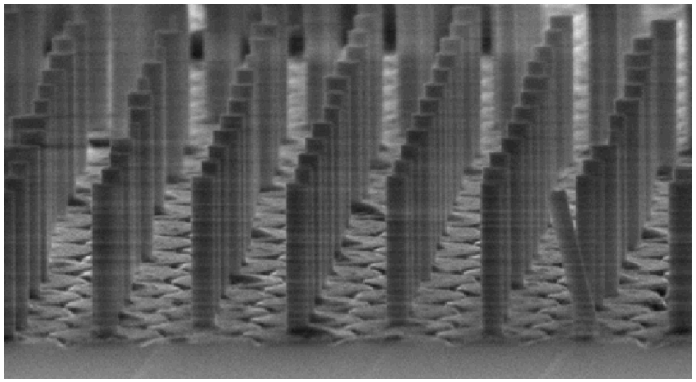
- Lasers for SSL
- Design: Slow Group Velocity Modes
- Fabrication: Top-down Nanowire Photonic Crystals
- Optical Characterization and Results

This work was supported by Sandia's Solid-State Lighting Science Energy Frontier Research Center, sponsored by the Department of Energy Office of Science. 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. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

SSLS EFRC | CHTM Center for High Technology Materials | CINT | THE UNIVERSITY of NEW MEXICO | Sandia National Laboratories

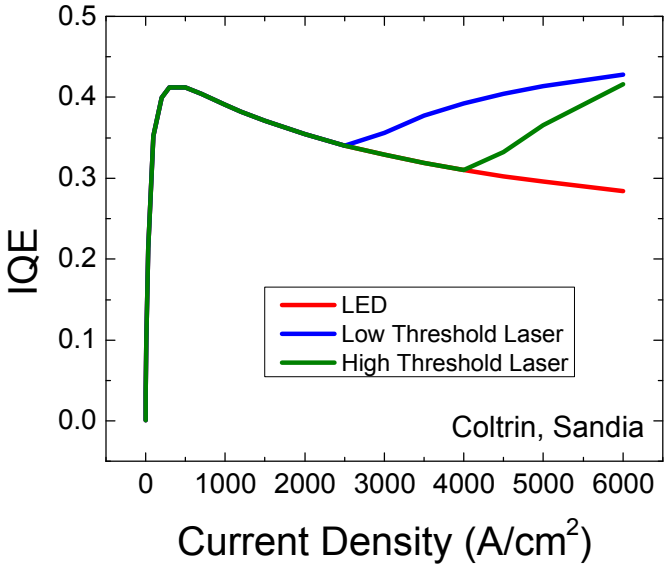
Why lasers in solid state lighting?

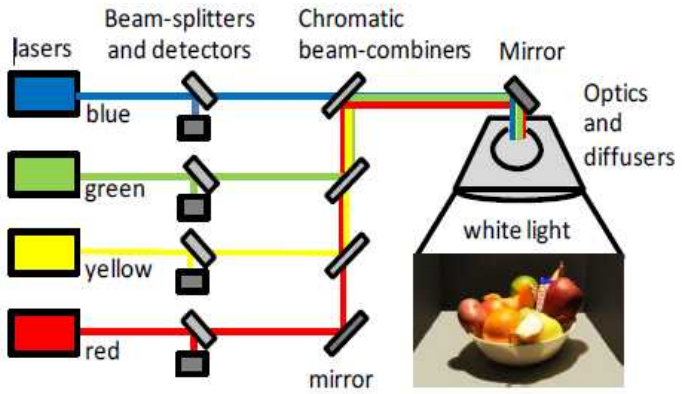
- The "efficiency droop"
  - InGaN LEDs exhibit a decrease in efficiency at high drive currents
  - limits the operating current density
  - increases the cost per lumen



Why Nanowires for Lasing?

- Reduced strain
  - Greater range of alloy compositions
- Integration into two-dimensional arrays

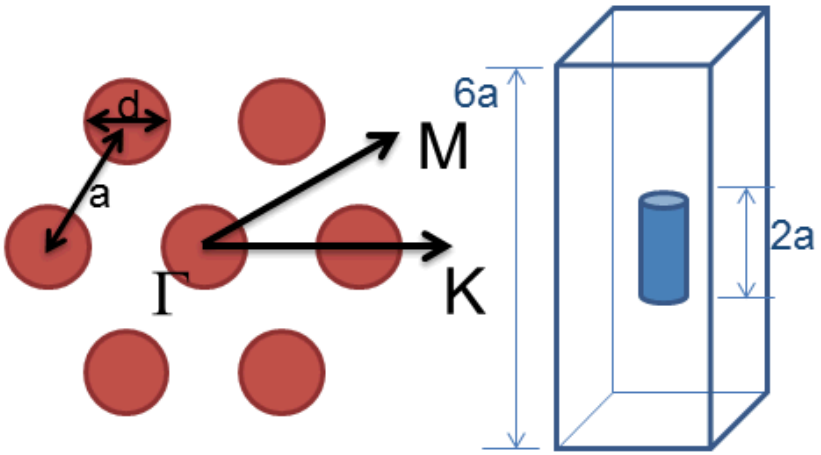


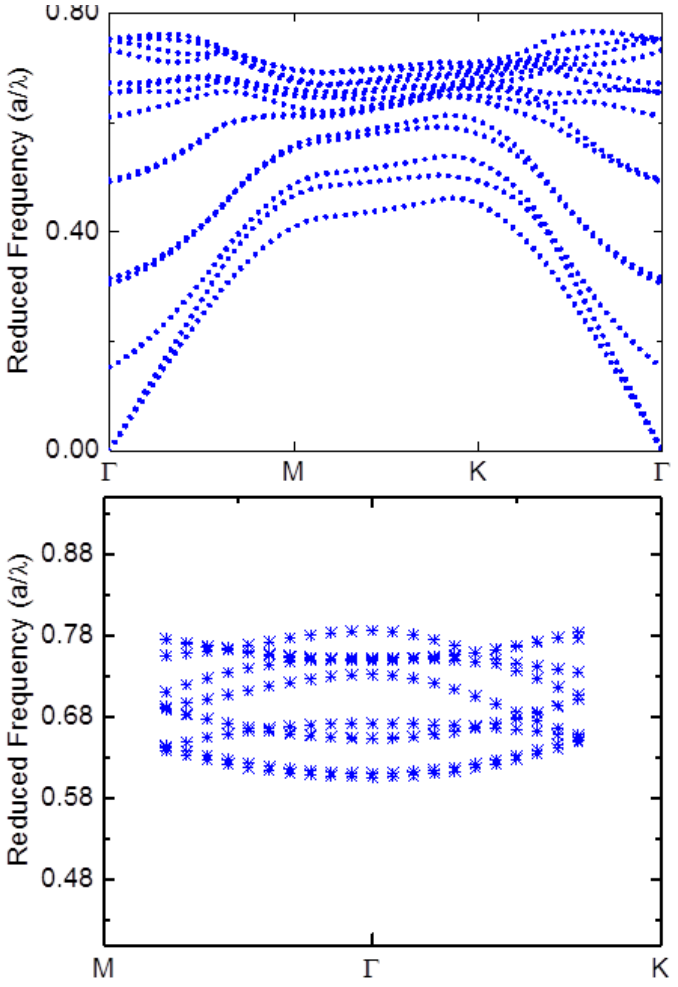


A. Neumann et al., "Four-color laser white illuminant demonstrating high color-rendering quality," Opt. Express, vol. 19, pp. A982-A990, 2011.

Designing vertically emitting photonic crystal lasers.

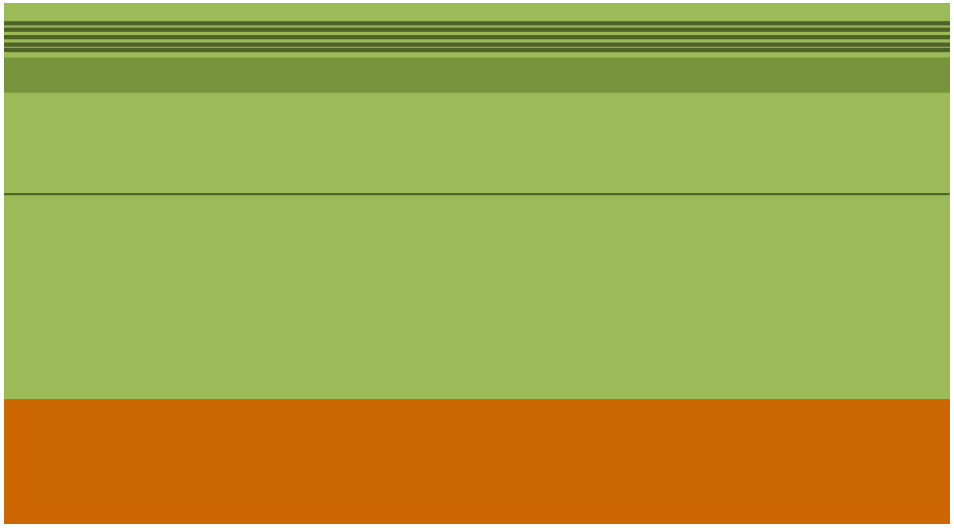
- We desire low group velocity
  - enhances the light matter interaction
  - forms standing waves within the gain medium
- We designed high order bands designed to have low dispersion

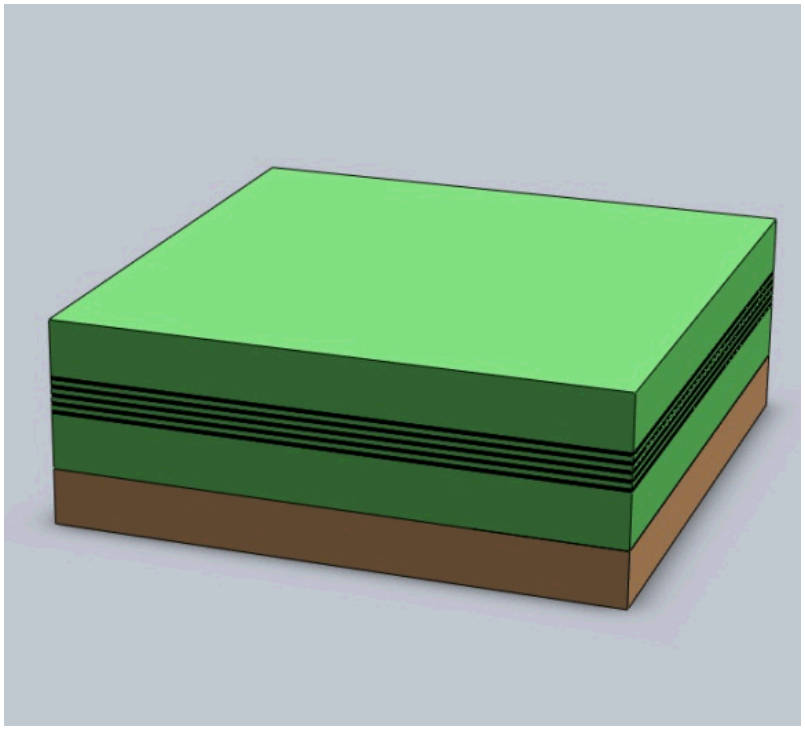




Fabrication | Growth of III-N active material

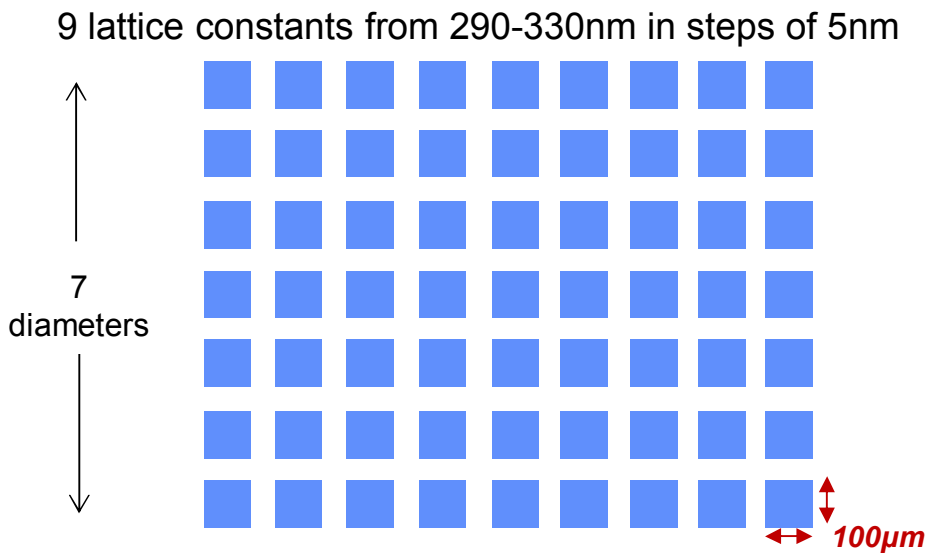
- 5 MQW InGaN/GaN near the surface
- 4μm GaN bufferlayer
- 2% In Underlayer

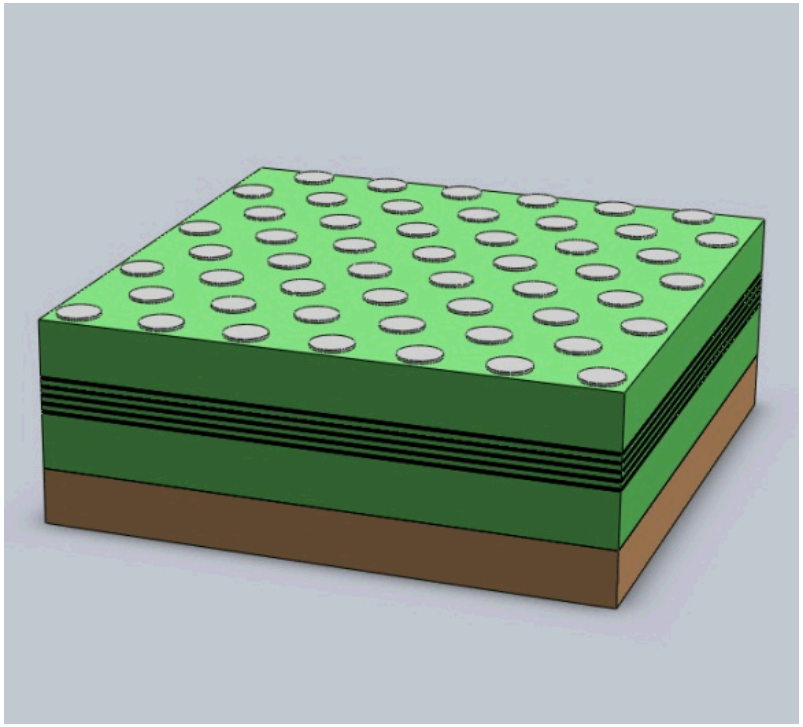




Fabrication | Patterning of 2DPC using e-beam

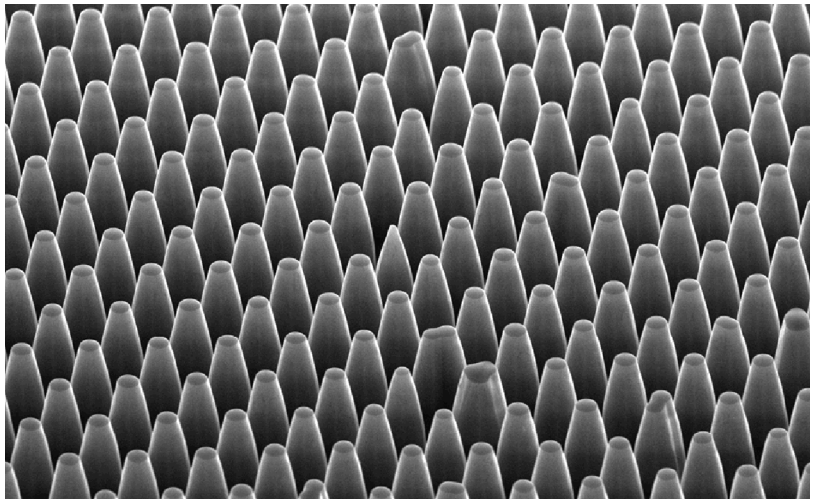
- **E-beam Patterning**
- **Triangular Lattice of Ni Dots**
- **9x7 array**

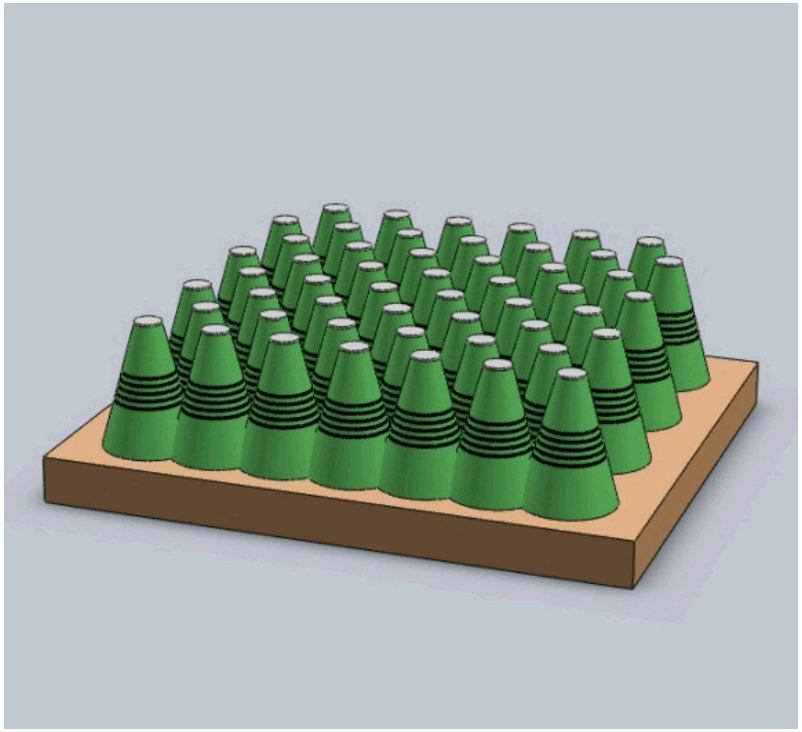




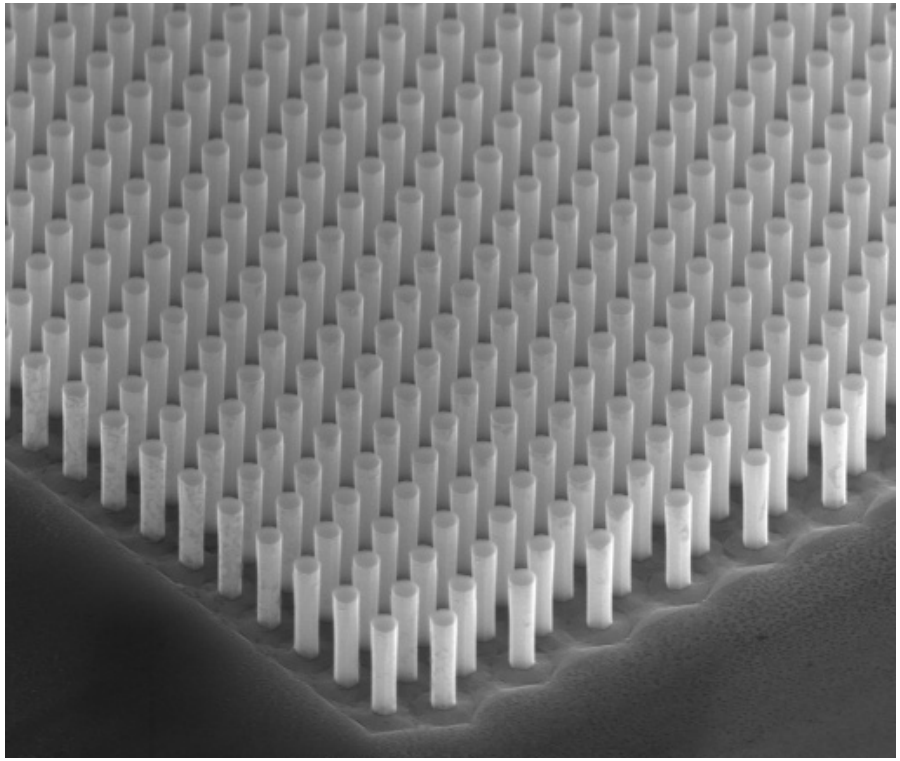
Fabrication | top-down 2-step etch process

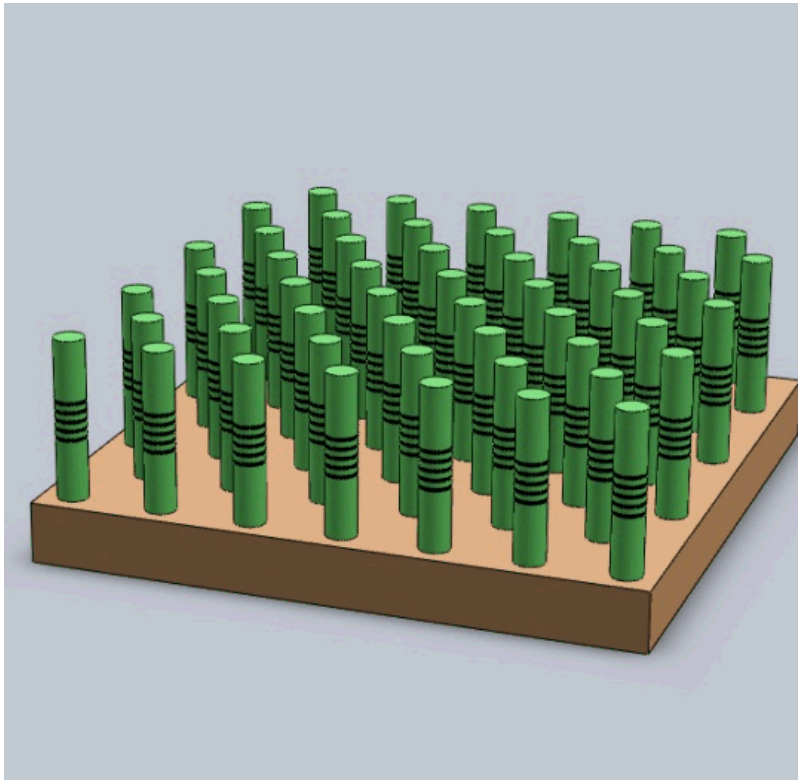
- Same process as our top-down nanowires
- Dry (ICP) followed by wet (KOH) process





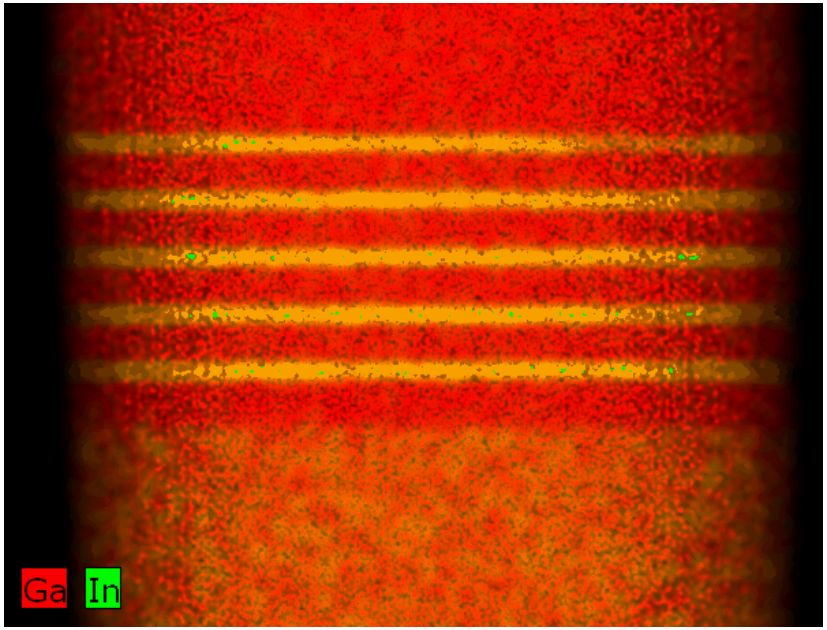
Fabrication | Ordered arrays of anisotropic nanowires

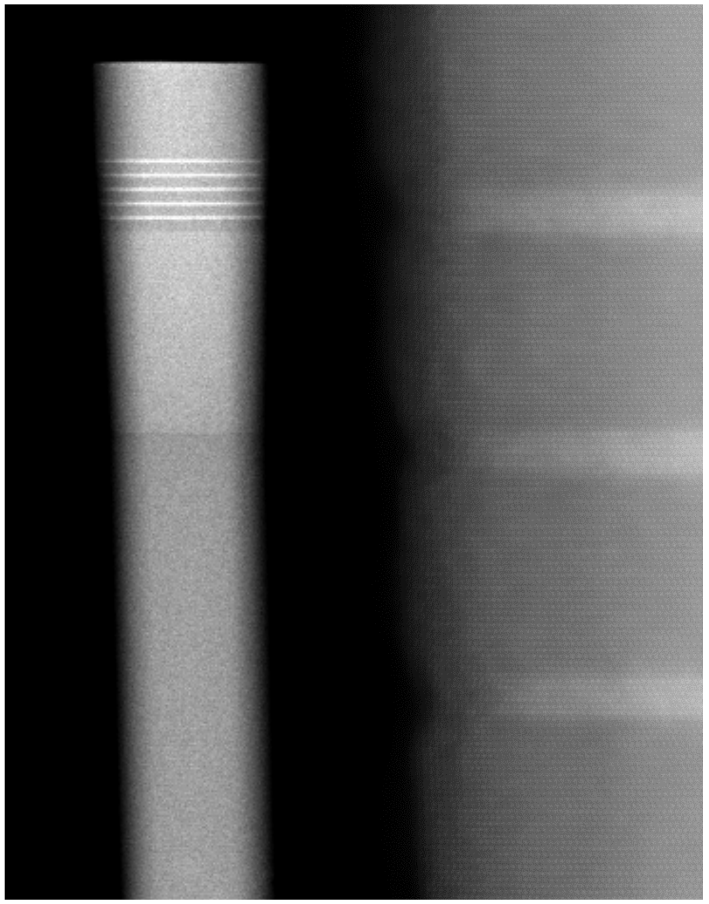




TEM of a single nanowire taken from an array

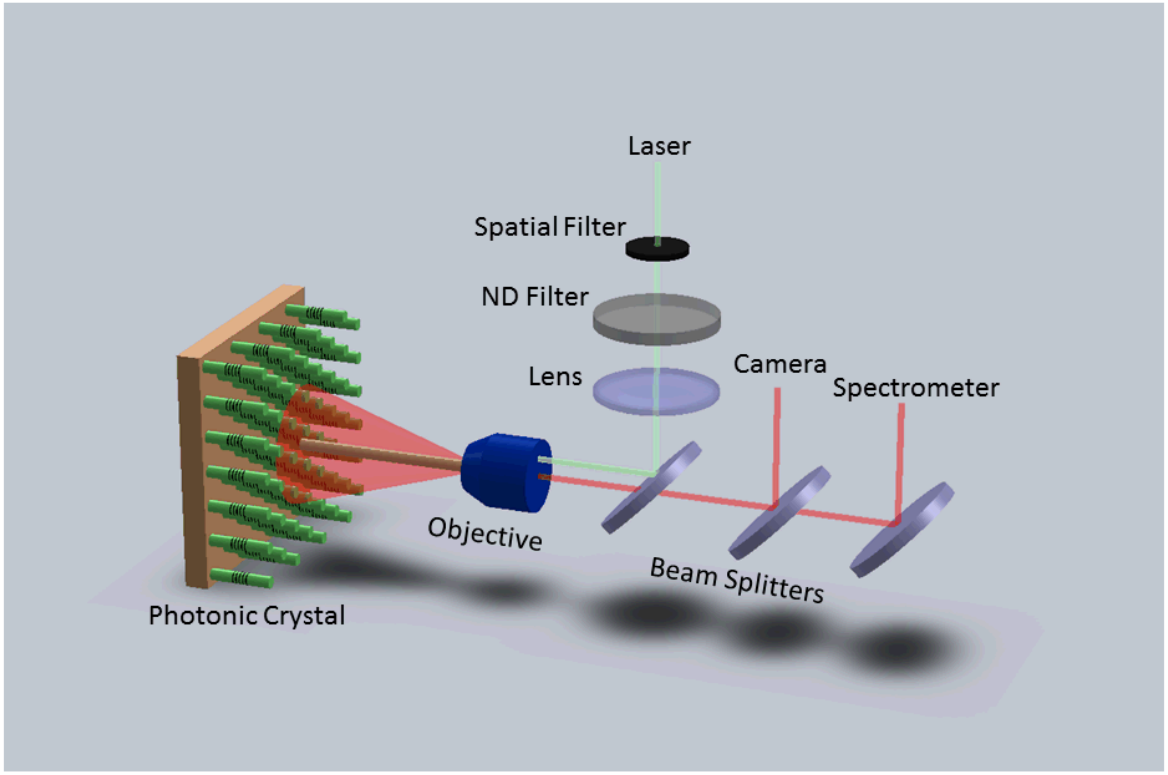
- 5x MQW InGaN Emission Centered at 430nm
- 2% In underlayer
- Slight taper from the InGaN quantum wells

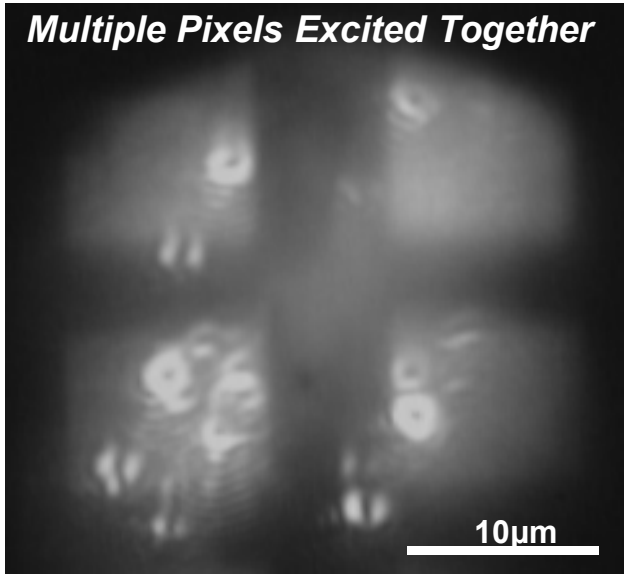




Ping Lu, Sandia

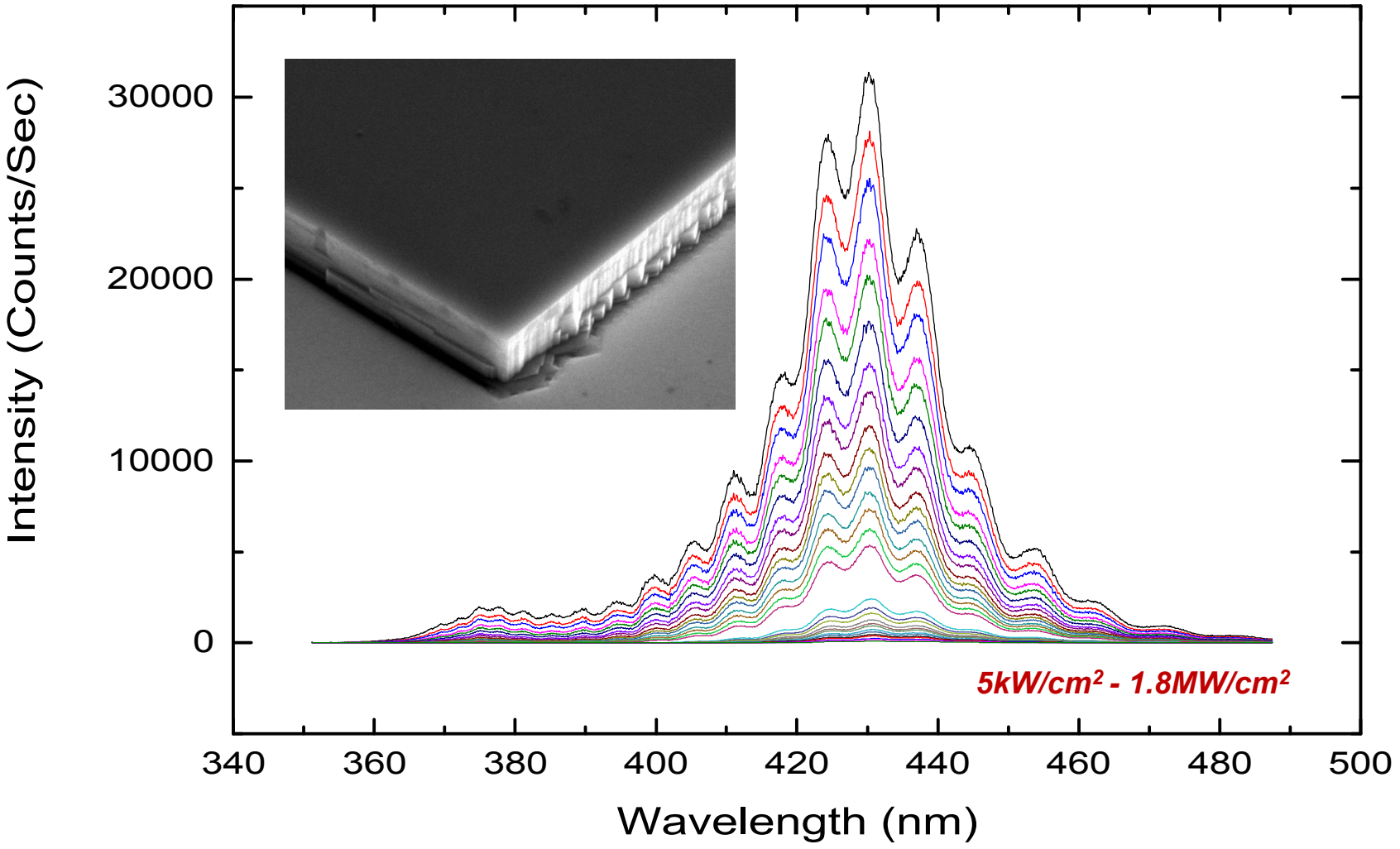
micro-Photoluminescent Optical Characterization



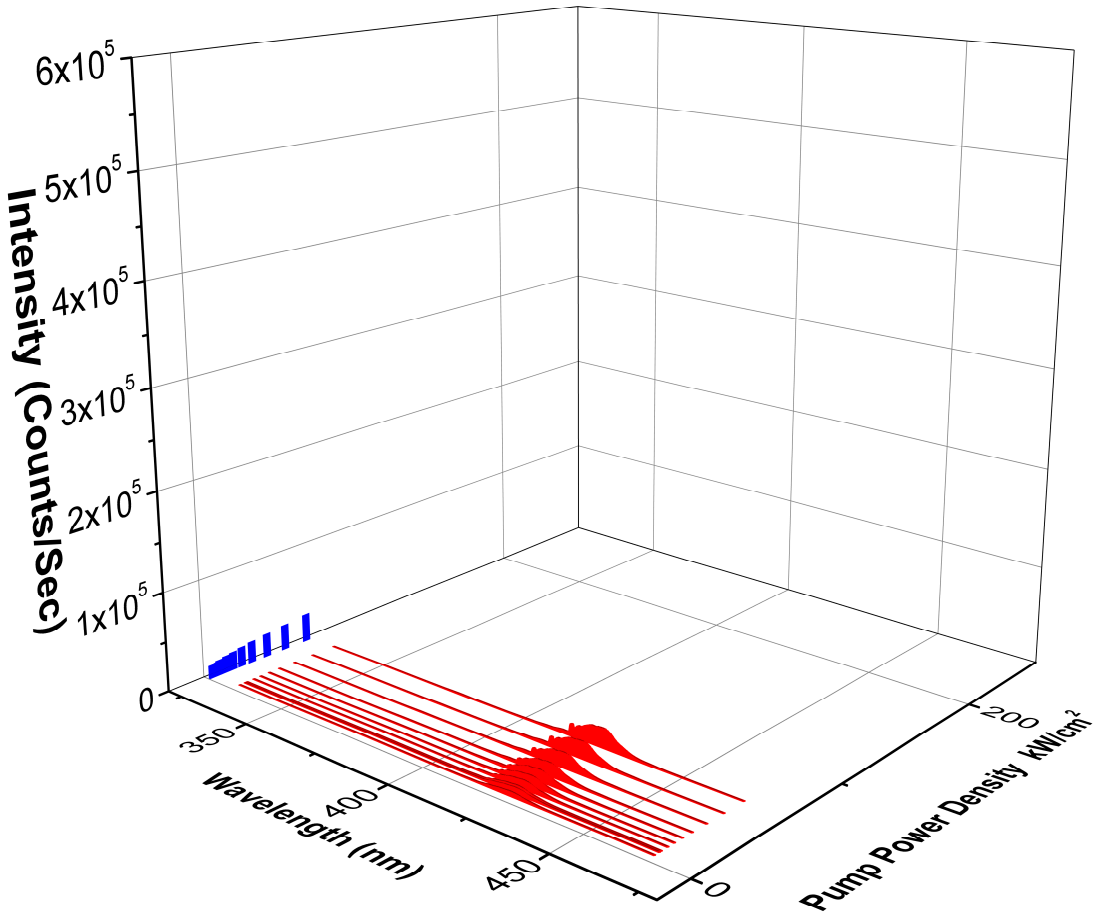


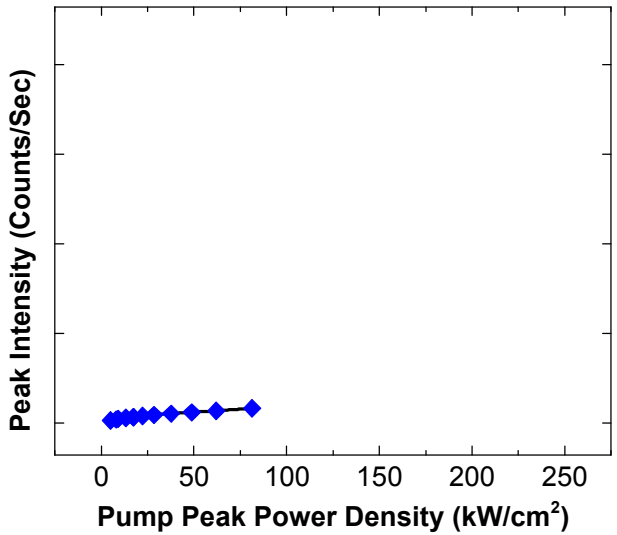
Pump spot is tunable in size and power density.

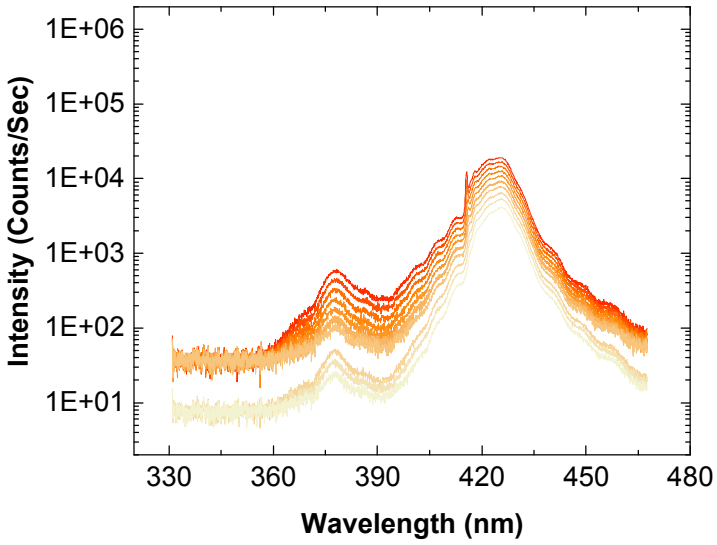
Photoluminescence from a non-etched reference region.



Below Threshold Spectra of a 2DPC Laser

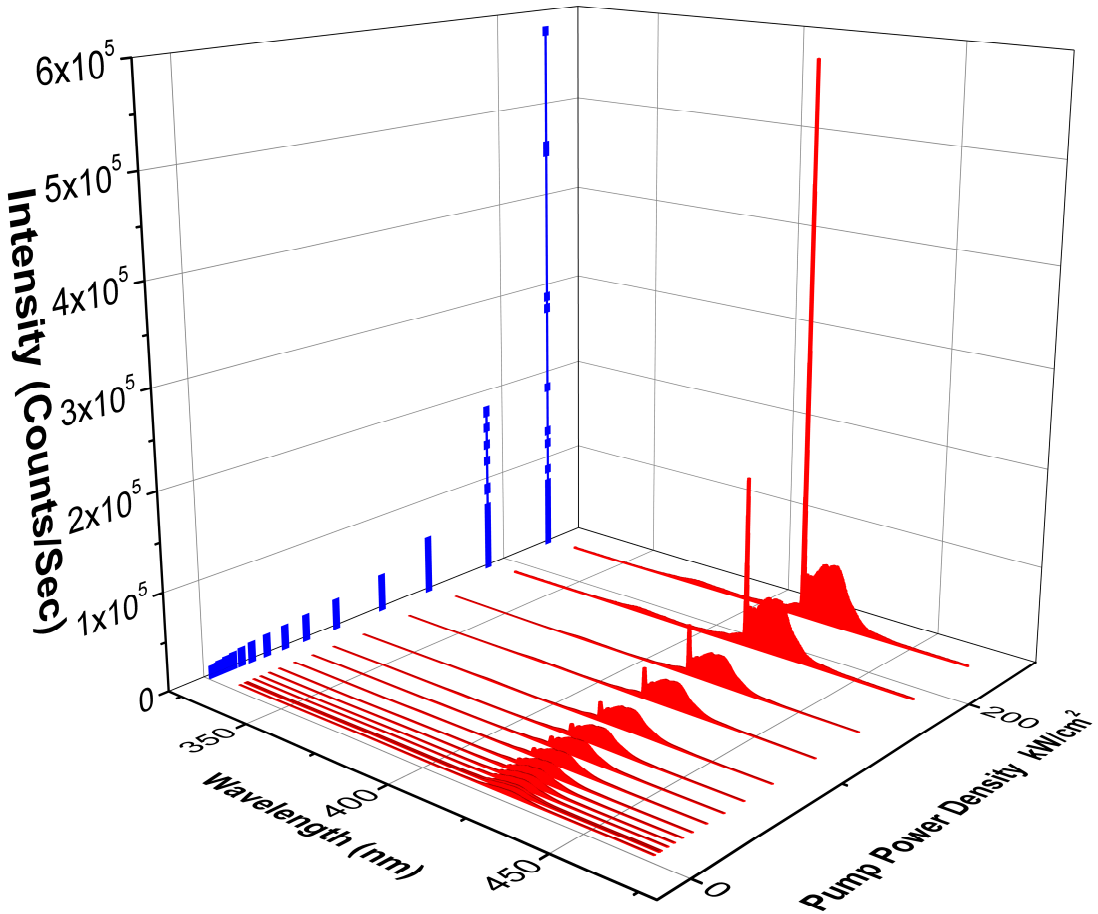


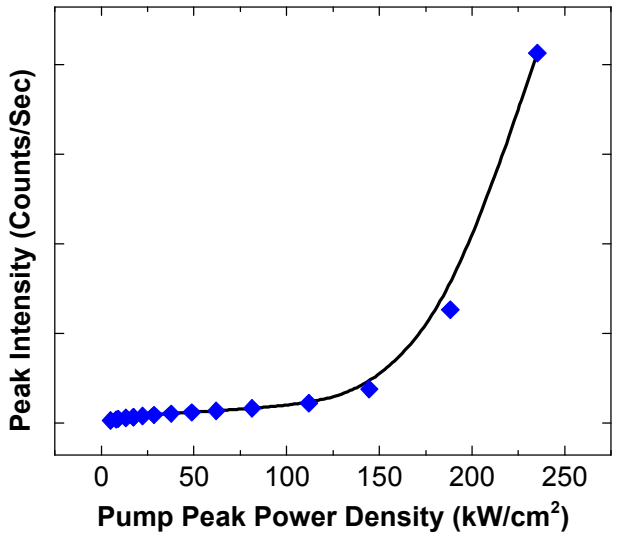


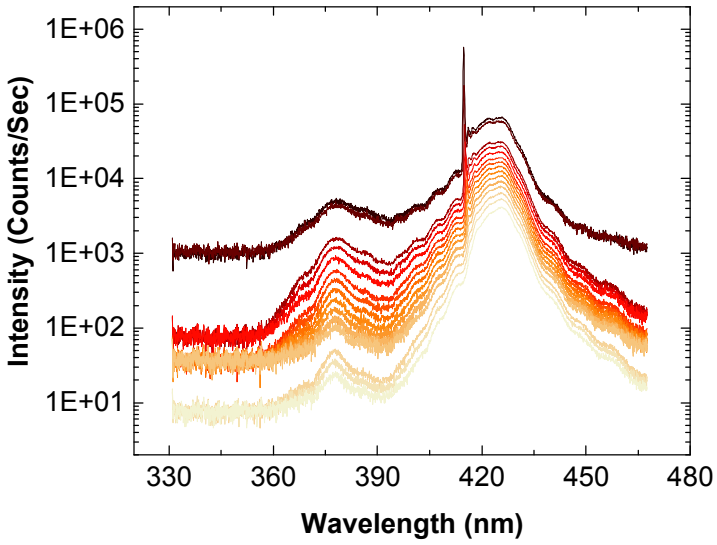


Array Element Dimensions: d=143 nm and a=320 nm.

Above Threshold Spectra of a 2DPC Laser

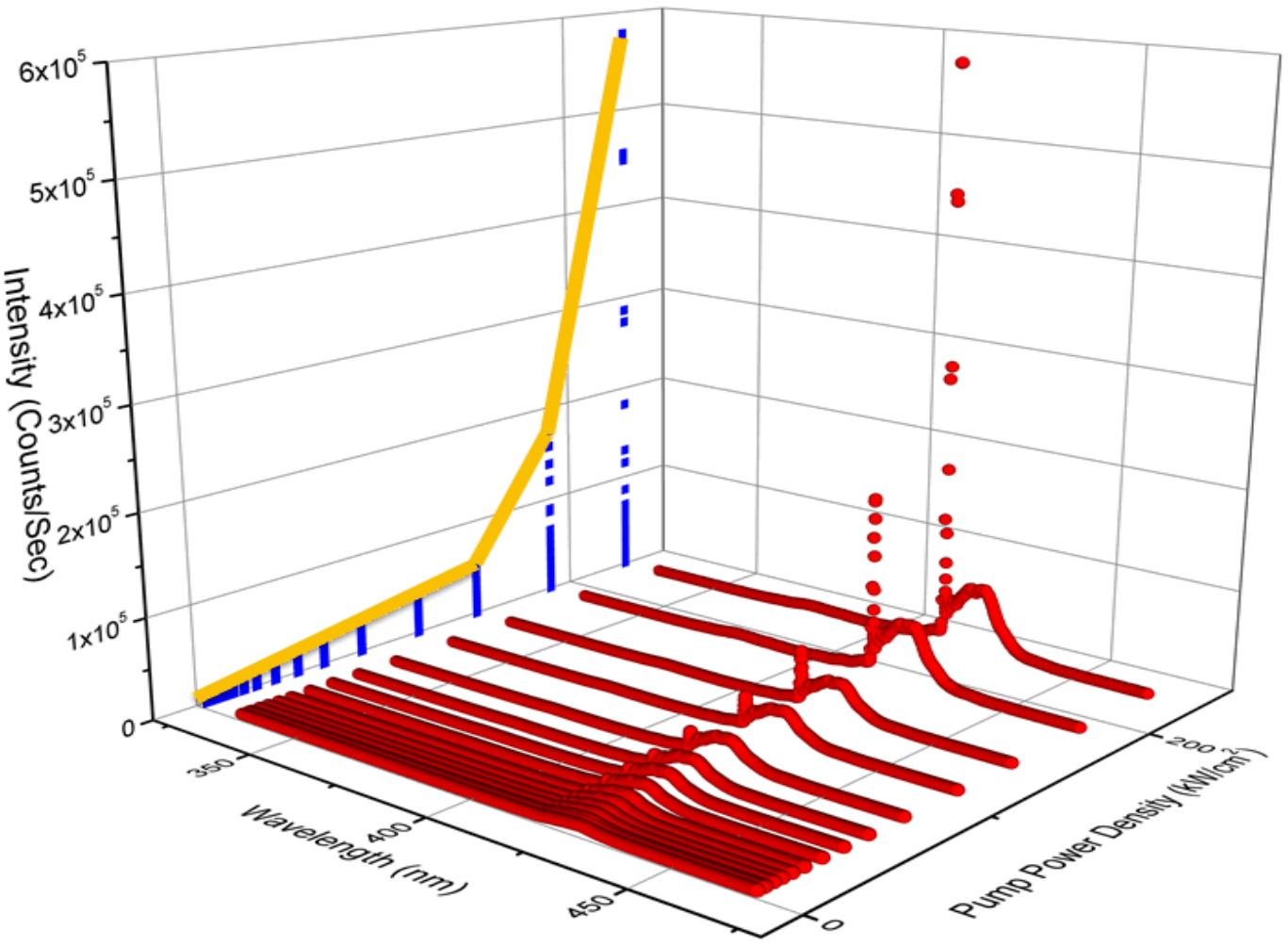






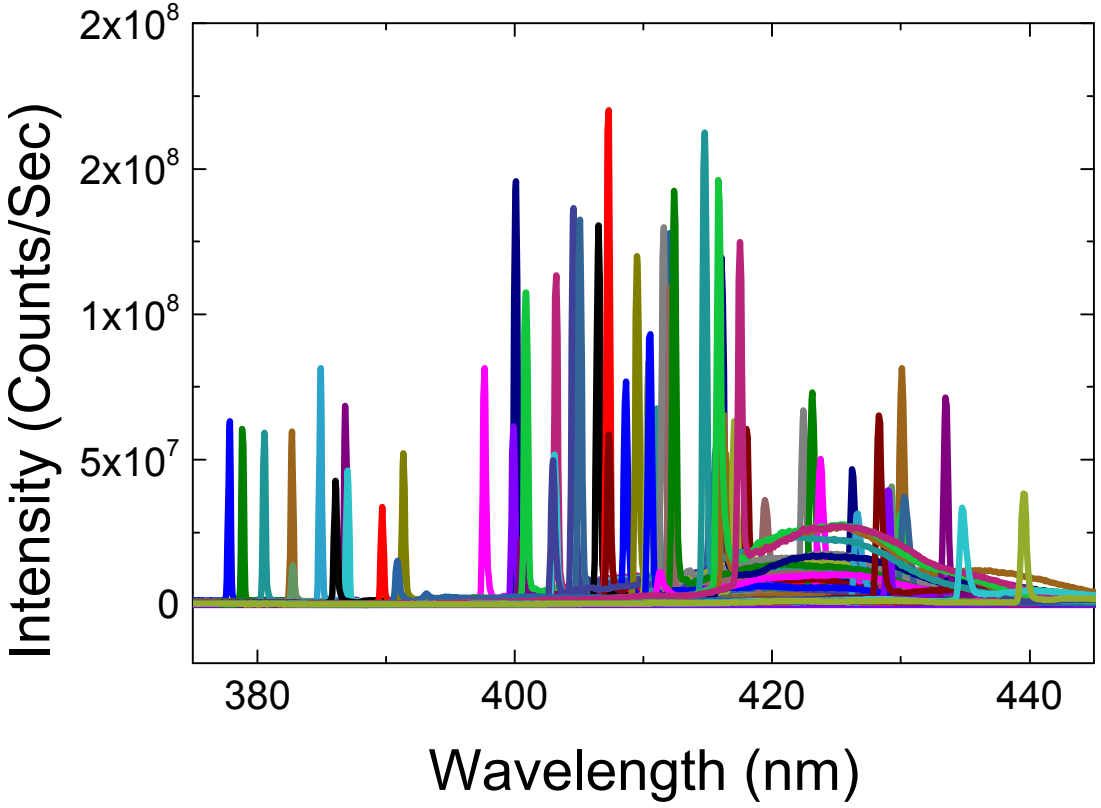
Array Element Dimensions: d=143 nm and a=320 nm.

Optical Results from a single array element



Array Element Dimensions: d=143 nm and a=320 nm.

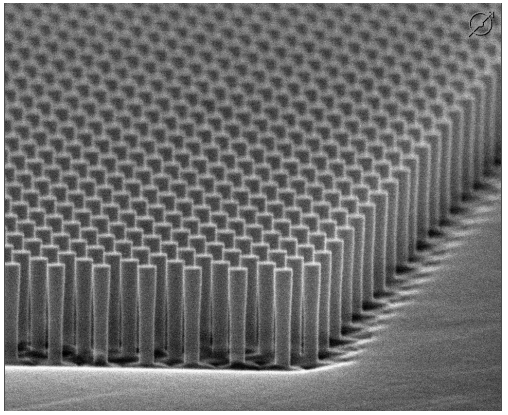
Multi-color Laser Array



- **Spectral Coverage from 380-440nm.**
- **Thresholds are reasonable compared to other optically pumped III-N nanowire devices. (<500kW/cm² for all devices)**

Summary

- Fabricated laser arrays that span a broad spectral range
  - Near-Vertical single-mode emitters
  - Thresholds are non-homogeneous but remain reasonable for optical pumping experiments
  - Possible to fabricate high density of emitters with a larger wavelength span
- Technology implications
  - Lasers for SSL
  - Displays and projectors



Thank you for your attention!

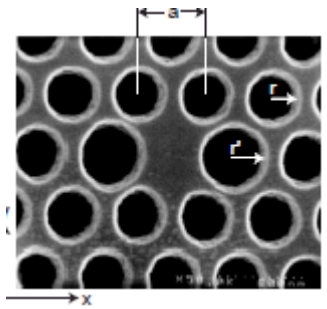
BACKUP MATERIAL

Future Directions

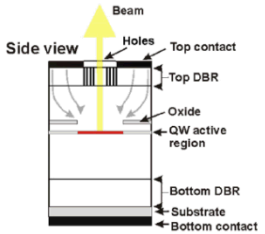
- Create a larger wavelength span in terms of PC structures and gain material.
- Reduction of Pixel Size
- Electrical Injection

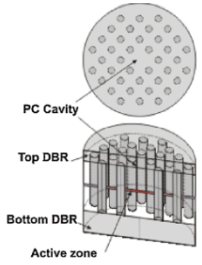
Previous Work

Most work on PCLs has been limited to Phosphides, Antimonides, and Arsenides. (λ>700nm.)



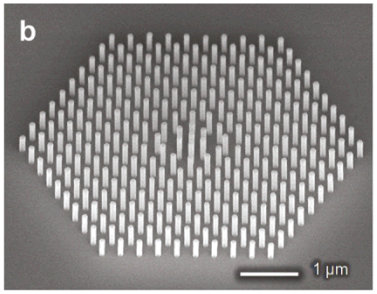
Painter, O. *et al. Science* ***284 (1999).***

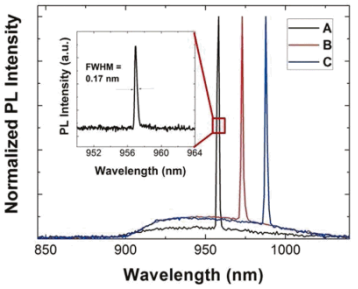




Ivanov et al…0268-1242_27_9_094010

Previous tuning results limited to <30nm

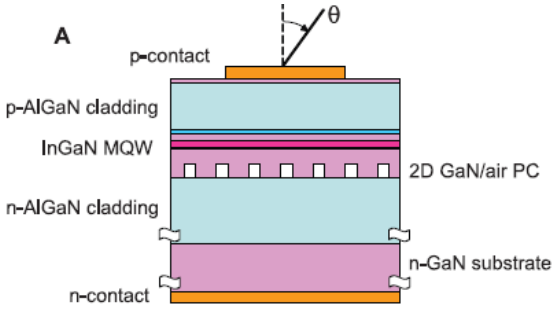


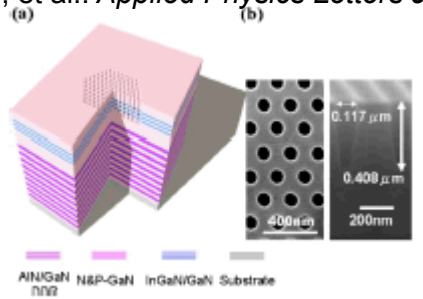


Scofield, A. C. *et al. Nano Lett.* ***11, (2011).***

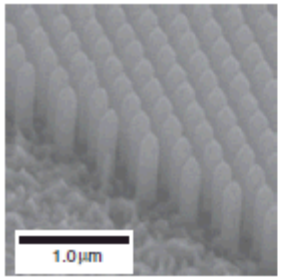
III-N difficult to fabricate or lack of tuning

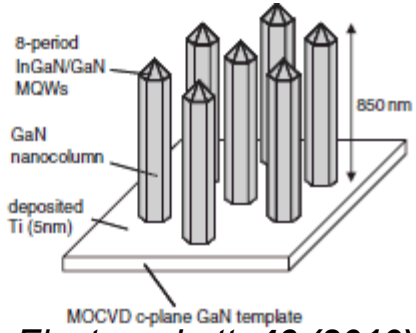
Lu, T.C., et al.. *Applied Physics Letters* ***93 (2008).***





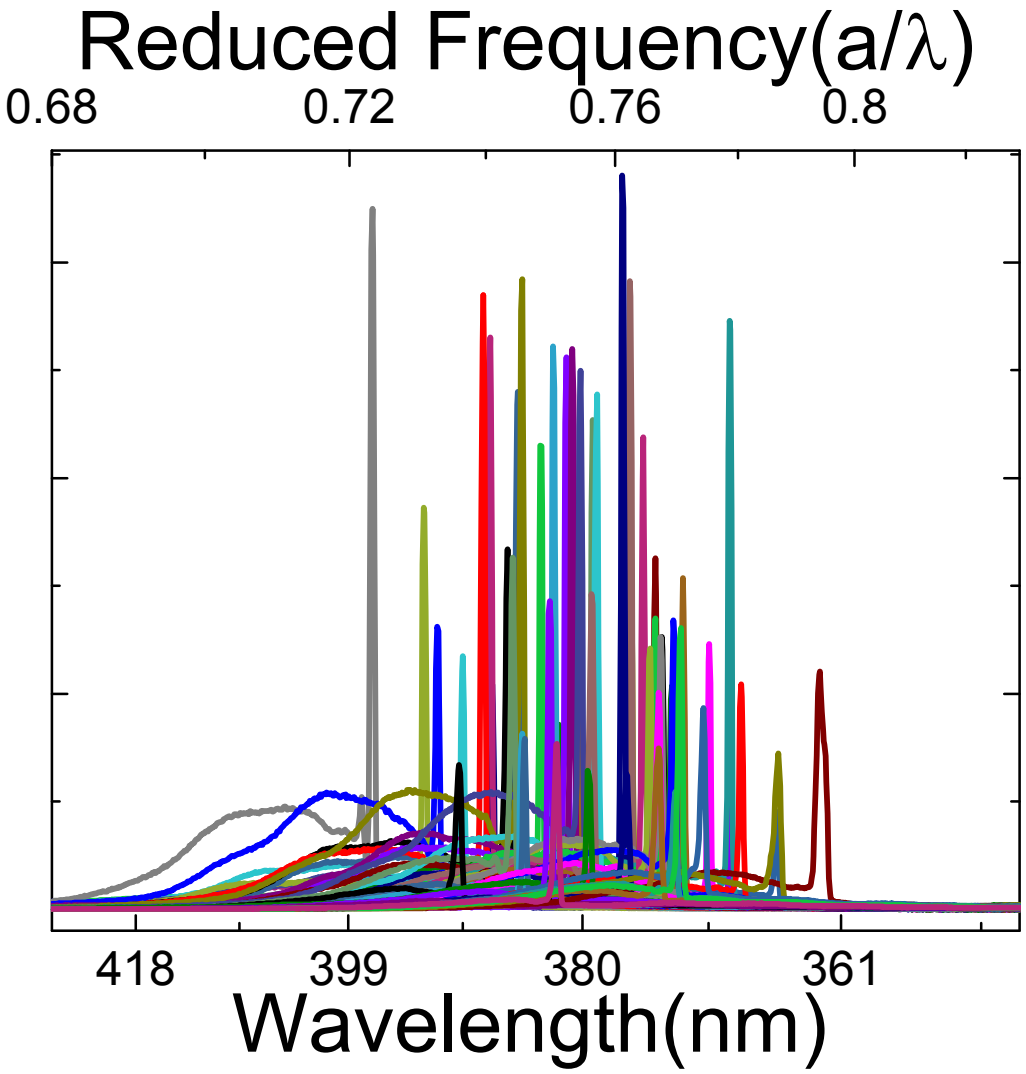
Matsubara, H. *et al.. Science* ***319, 445-447, (2008).***



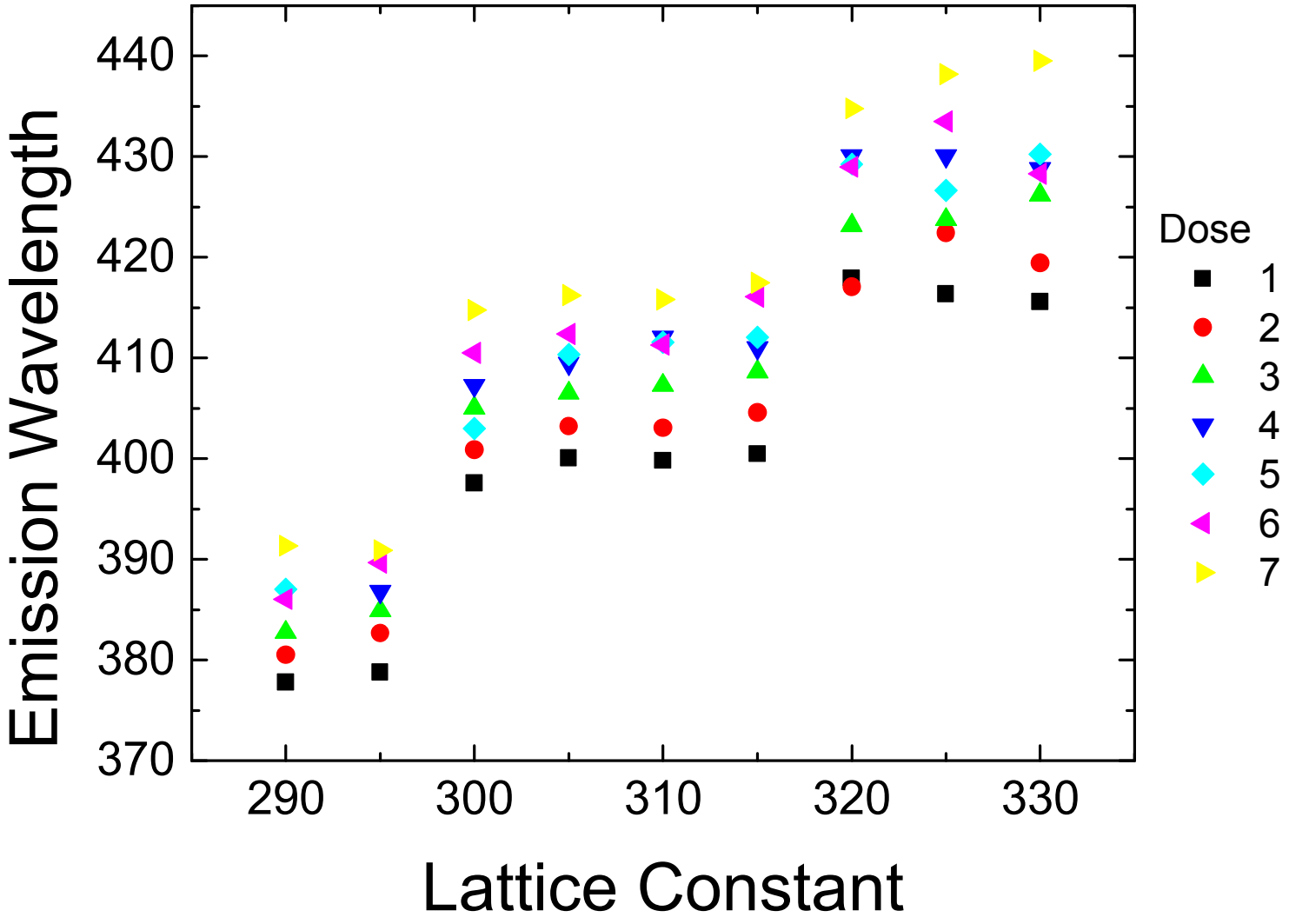


Kouno, T. *et al. Electron. Lett.* ***46 (2010)***

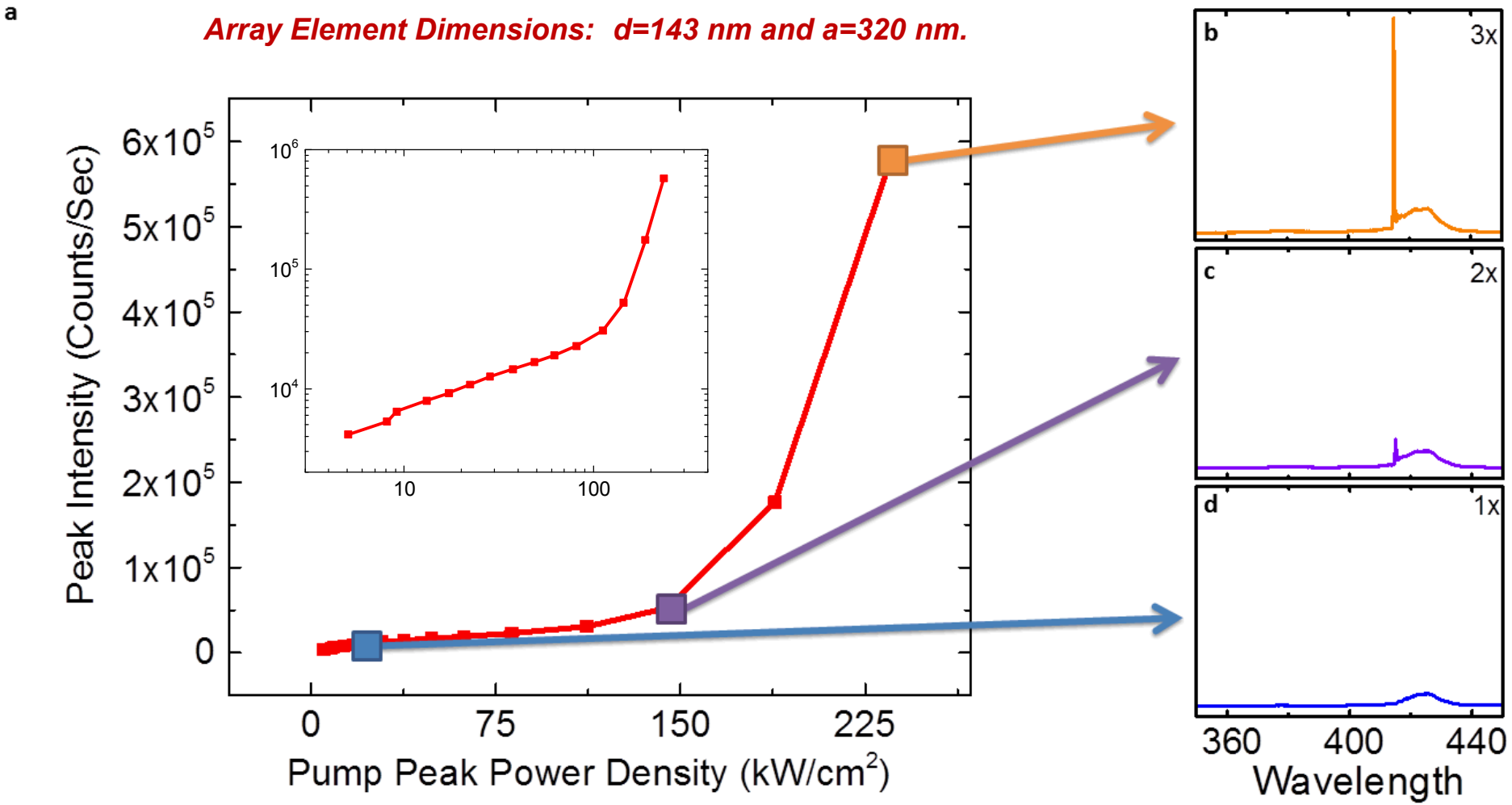
Lasing as a function of reduced frequency



Lasers



Optical Results from a single array element



Motivation

- **Fabricate an array of different color lasers on a single chip that emit vertically with single-mode operation.**
- **Ideal spectral coverage would span the visible wavelengths.**
- **Optical Information Processing, Biology, Solid State Lighting, and Displays**