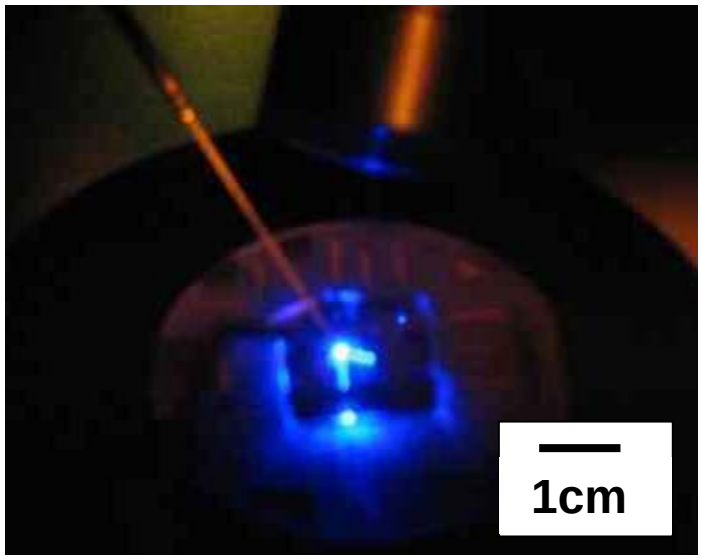
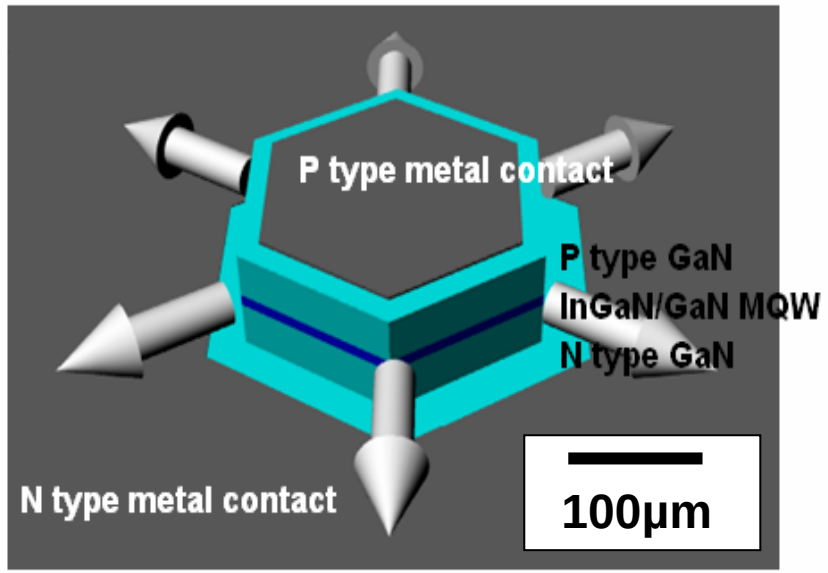
Hexagonal Prism Blue Laser using Whispering Gallery Mode (WGM) Resonances





Sangho Kim
Advisor: Prof. Tim D. Sands
School of Electrical and Computer Engineering
Birck Nanotechnology Center
Purdue University Feb 1 2007

Outline

- Current semiconductor laser technology
  - applications
  - laser structures

- Hexagonal prism laser
  - advantages
  - selective epitaxial growth
  - etching process

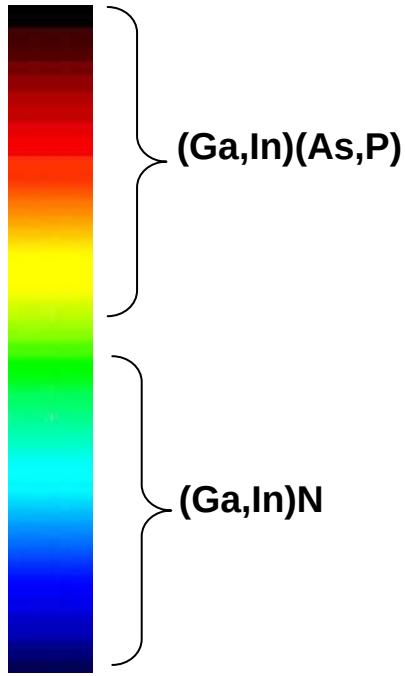
- Characterization of hexagonal prism laser
  - threshold (nonlinearity, FWHM shrinkage) and directionality

- Advantages and potential applications

Current Applications of Semiconductor Laser Devices

- Long distance fiber optic communication
- Short distance optical interconnection
- Optical storage
- Displays
- Molecular detection devices
- Printing

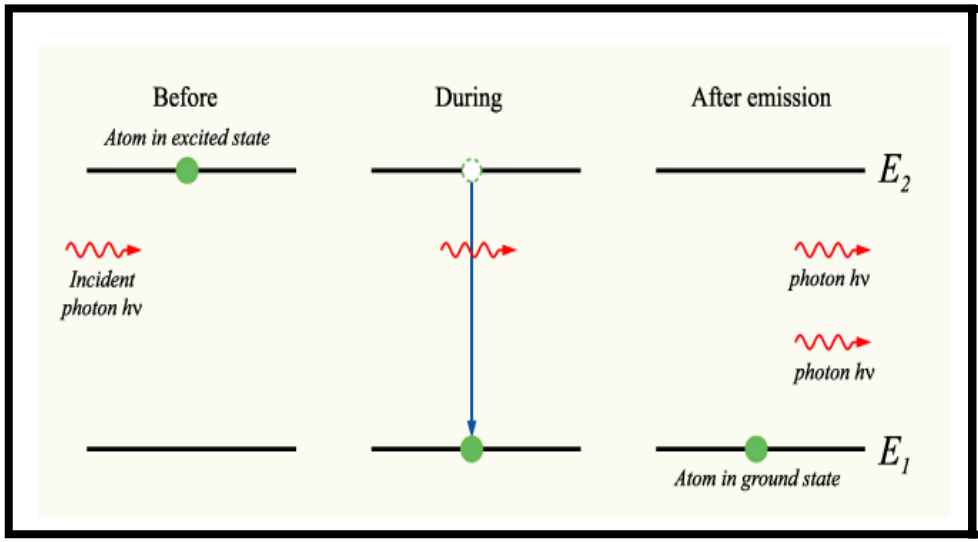
Current Technology

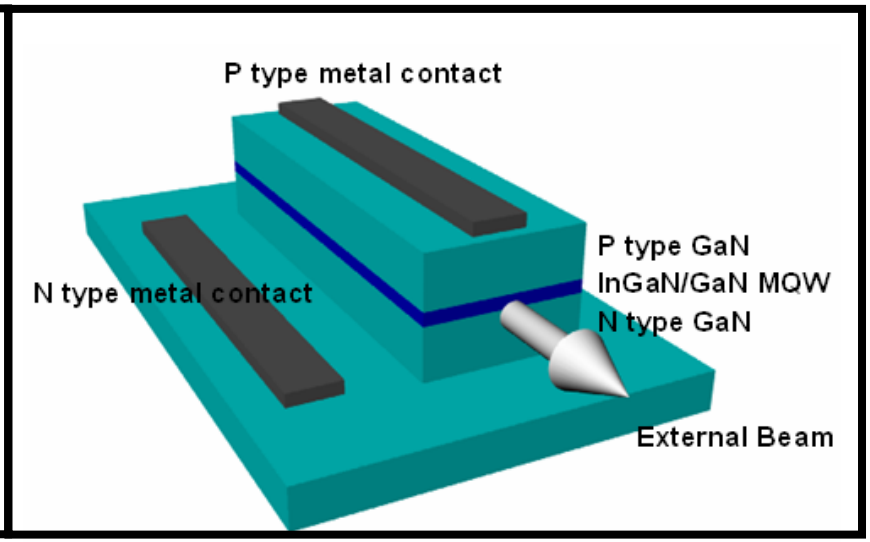


Lower power consumption blue laser

Edge-emitting laser

- Spontaneous emission
  - •excited electrons recombine with holes, emitting incoherent photons
- Stimulated emission
  - •when perturbed by a photon, recombination generates another photon that has same phase and frequency as the original (coherent).

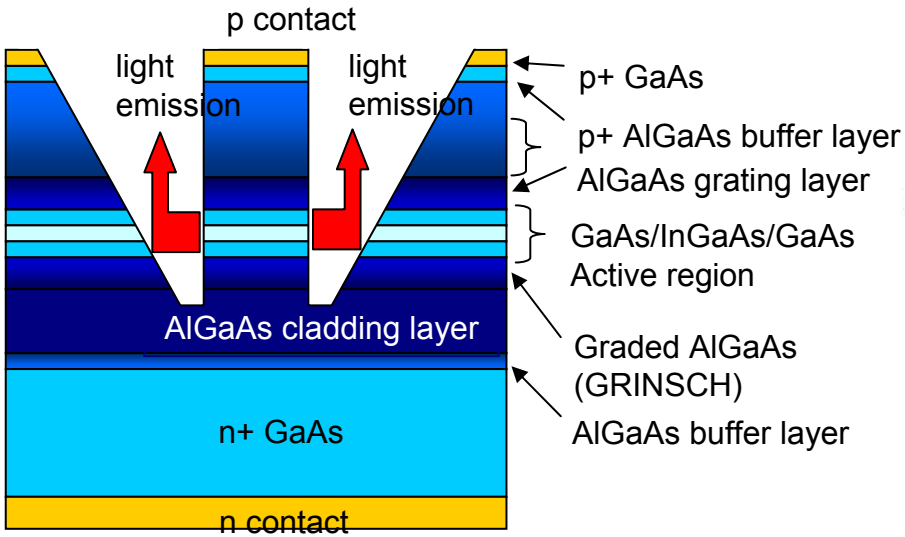




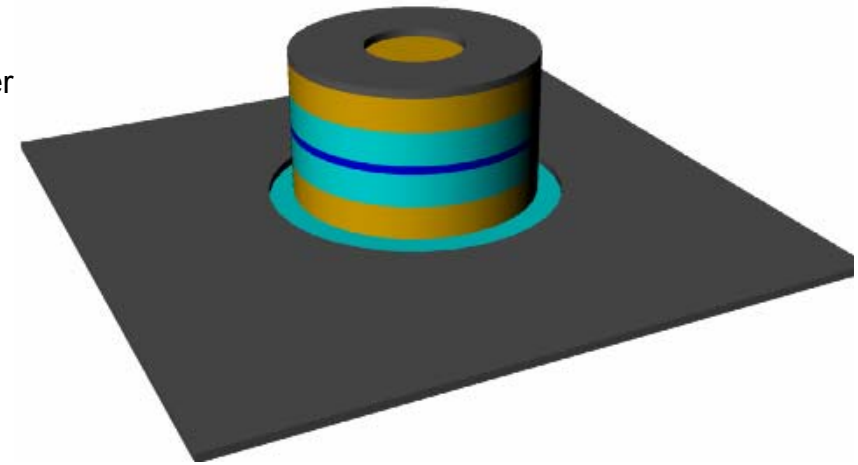
Pros: 1. Simple fabrication process.
2. High output power

Cons: 1. horizontal beam.
2. Relatively large device size

Surface emitting laser devices



Beam Deflector Surface Emitting Laser (BD-SEL)

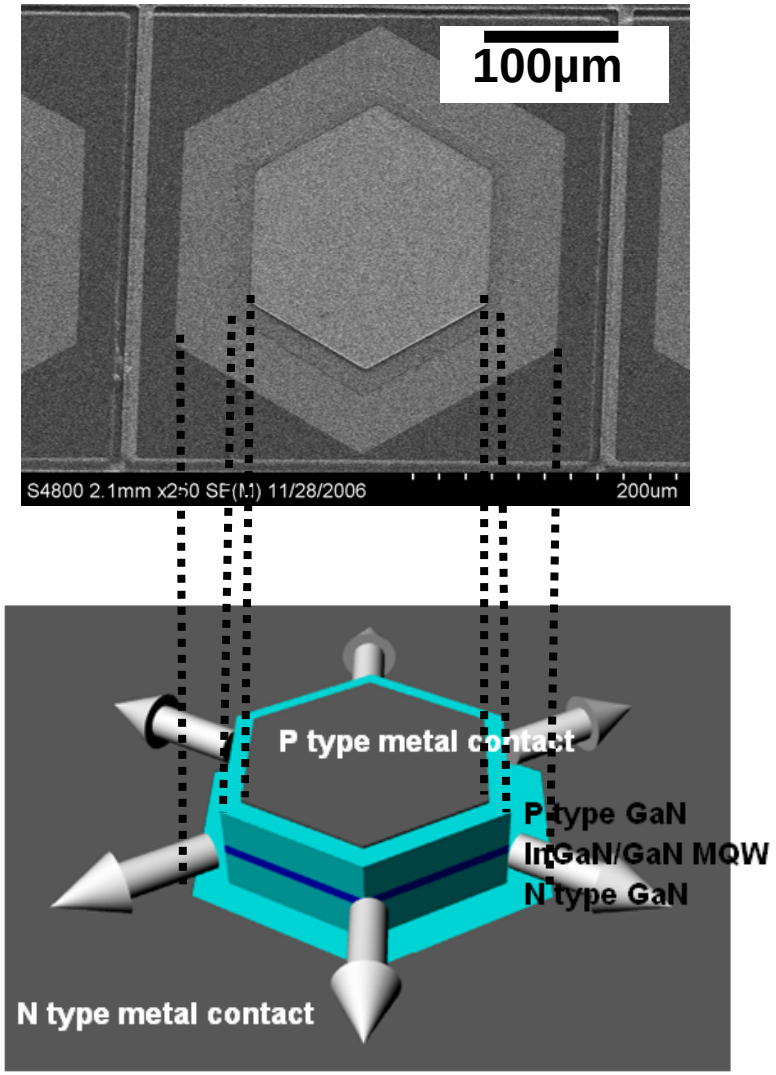


Vertical Cavity Surface Emitting Laser (VCSEL)

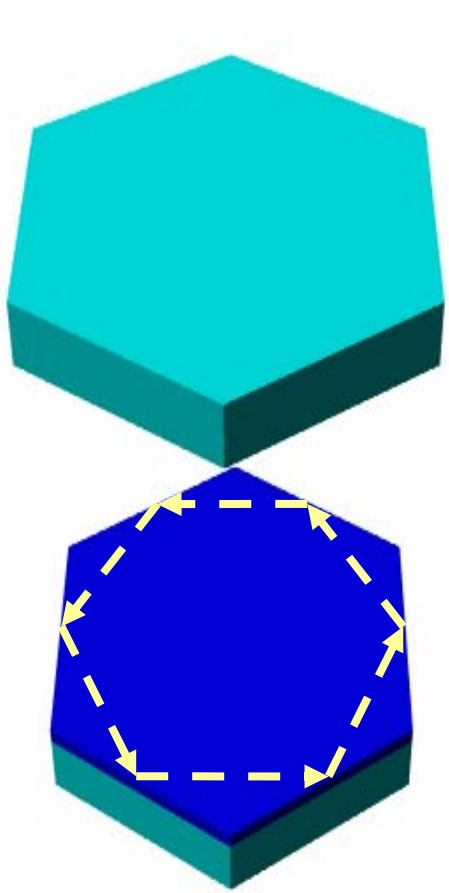
using

- High quality DBR
  (distributed bragg reflector)
  which requires
  - Low dislocation density superlattice
  - Electrically conductive

Hexagonal Prism Laser

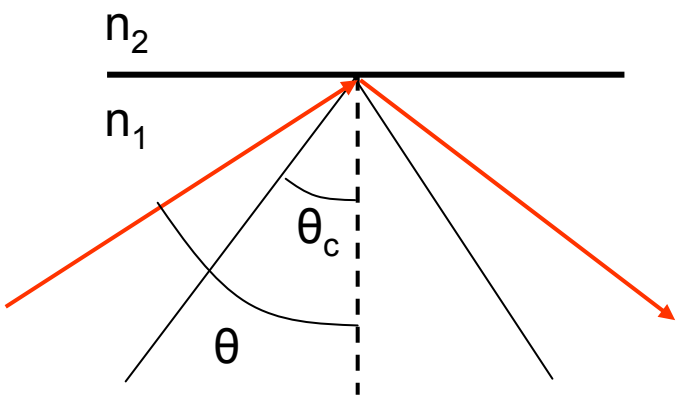


Schematic of hexagonal prism

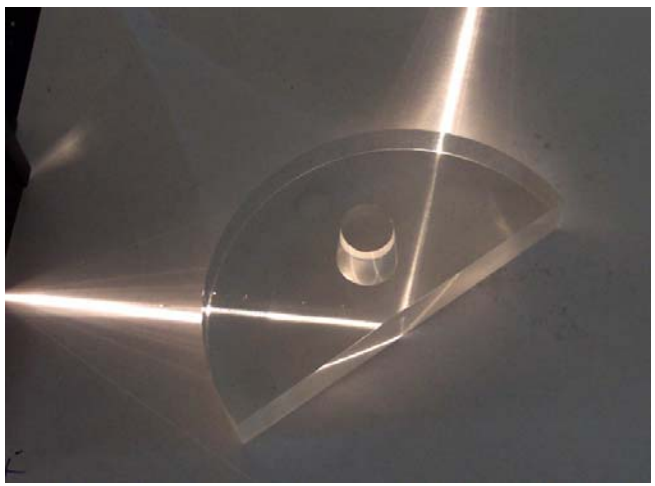


WGM (whispering gallery mode)
Resonance path
in MQW (active) region

TIR (total internal reflection) and WGM (whispering gallery mode) under closed geometry

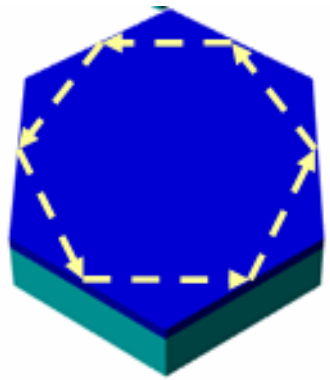


$\Theta > \Theta_c = \arcsin(n_2/n_1)$
where, $n_1 > n_2$



http://en.wikipedia.org/wiki/Image:Total_internal_reflection.jpg

St. Paul Cathedral Church
http://www.sacred-destinations.com/index.html



WGM optical resonance path

Outline

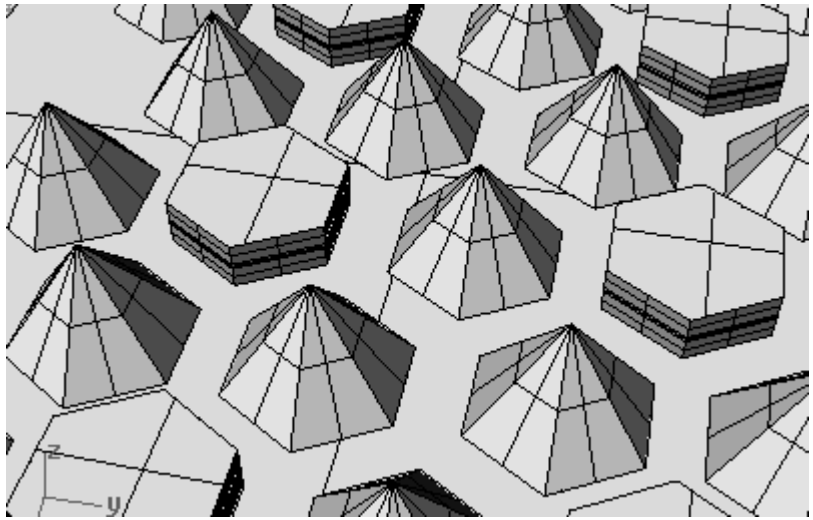
- Current semiconductor laser technology
  - applications
  - laser structures

- Hexagonal prism laser
  - advantages
  - selective epitaxial growth
  - etching process

- Characterization of hexagonal prism laser
  - threshold (nonlinearity, FWHM shrinkage) and directionality

- Advantages and potential applications

Vertical Emitting Laser Device?

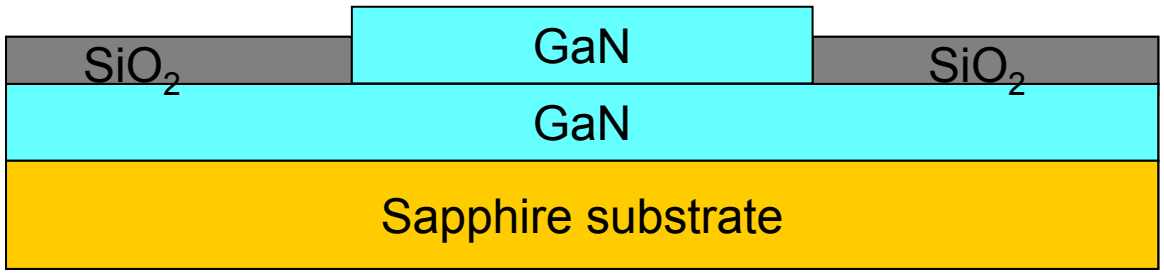


Vertical Emitting array Device

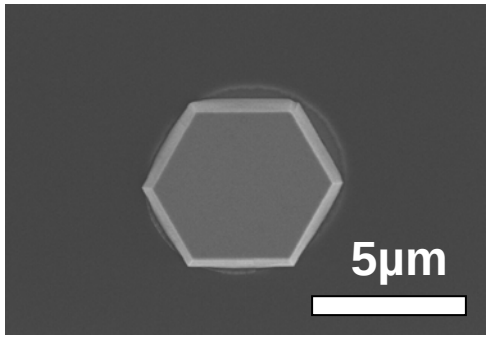
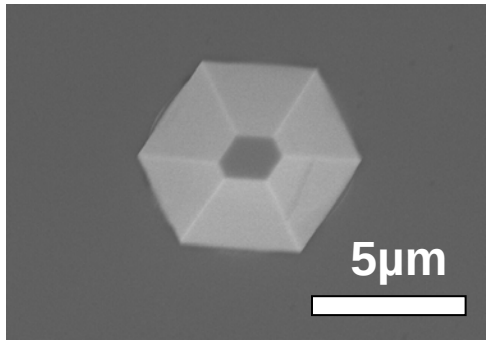
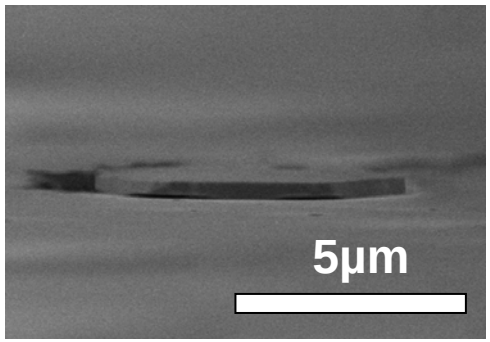
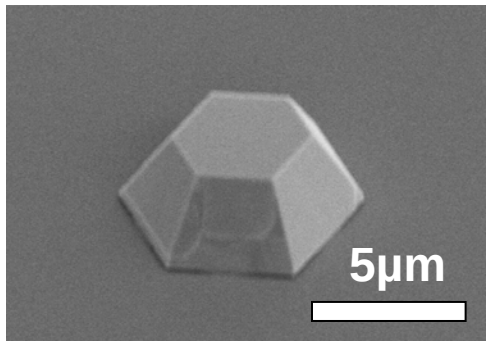
Using
Hexagonal Prisms and Hexagonal Pyramids

Selective Epitaxy Growth (SEG) Method

Hexagonal prism and pyramid structure growth using OMVPE



Growing Prism and Pyramid using SEG method

	Hexagonal Prism : OMVPE (1020C,100mbar)	Hexagonal Pyramid : OMVPE (950C, 250mbar)
Top View		
Side View		

Advantages over etching approach

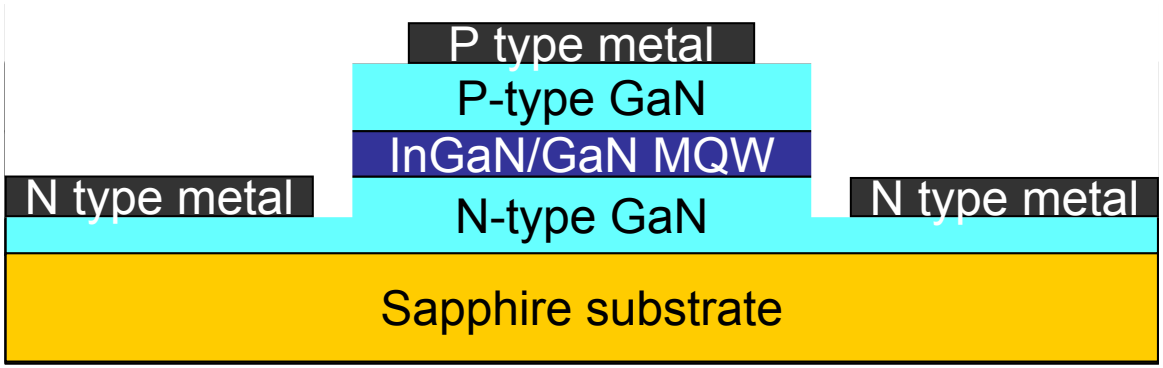
- **neither DBR nor additional packaging process needed for vertical emission**
- **single substrate**
- **atomic flat surface**

Outline

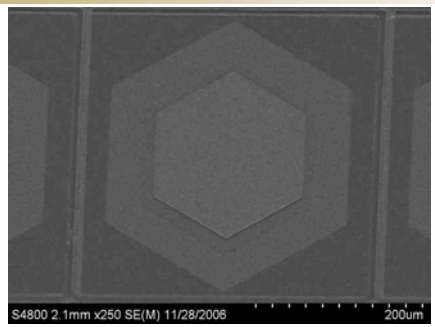
- Current semiconductor laser technology
  - applications
  - laser structures
- Hexagonal prism laser
  - advantages
  - selective epitaxial growth
  - etching process
- Characterization of hexagonal prism laser
  - threshold (nonlinearity, FWHM shrinkage) and directionality
- Advantages and potential applications

Fabrication Processes (etching approach)

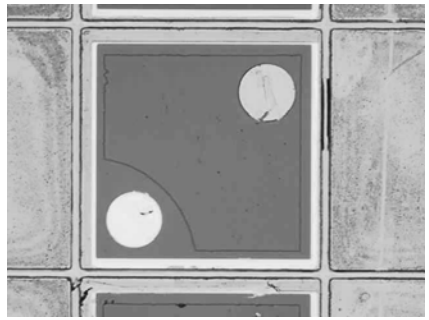
1. LED substrate
2. SOG coating on substrate
3. Optical Lithography and Wet Etching
4. ICP-RIE etching
5. SiO2 removal
6. Metal contacts deposition



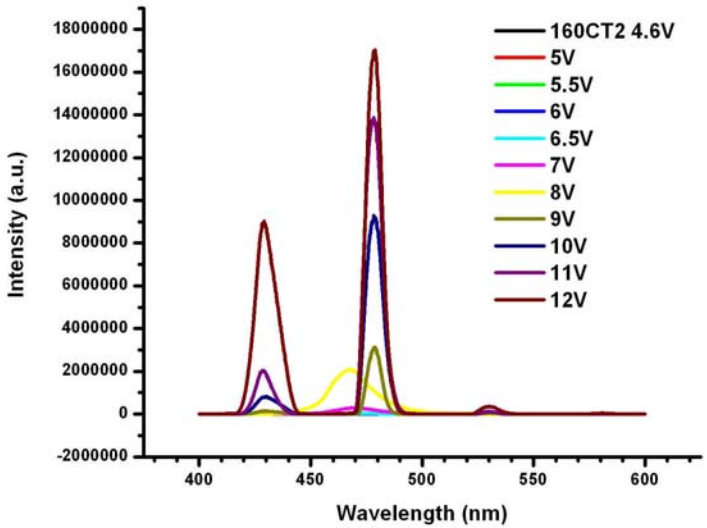
Laser vs. LED

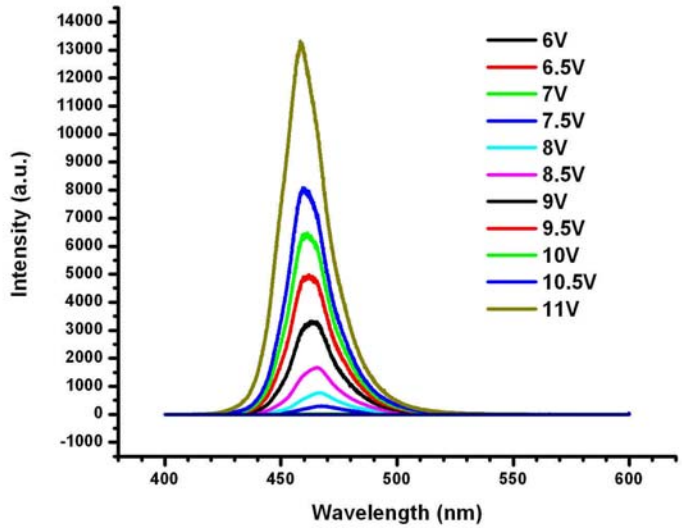


Hexagon Laser



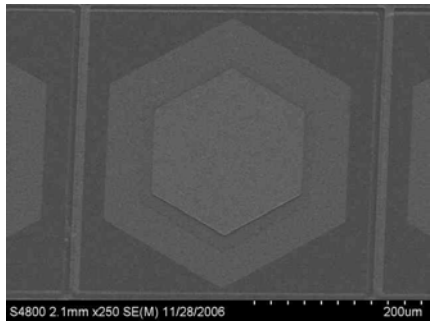
Plane LED



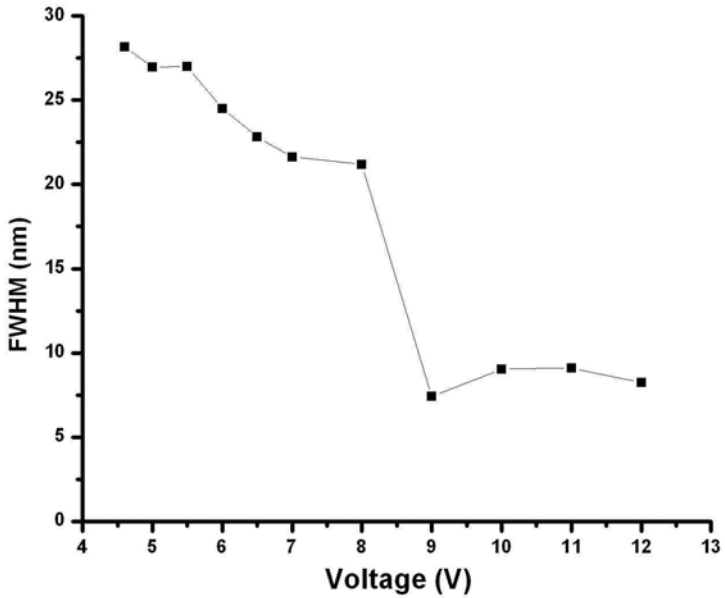


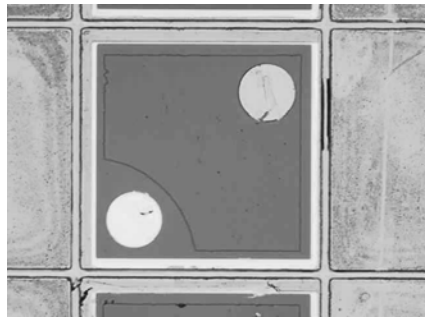
Laser Properties 1 Non-Linearity 2. FWHM 3. Directionality

Laser? How does a laser differ from an LED?

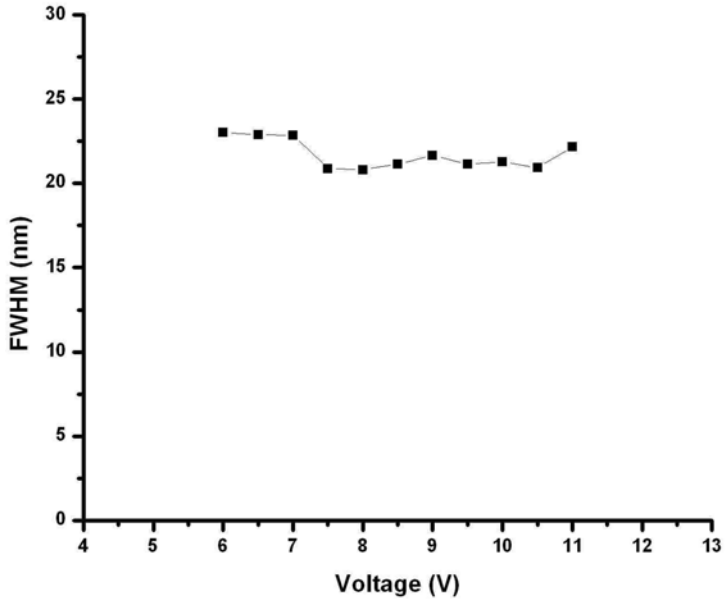


Hexagon Laser



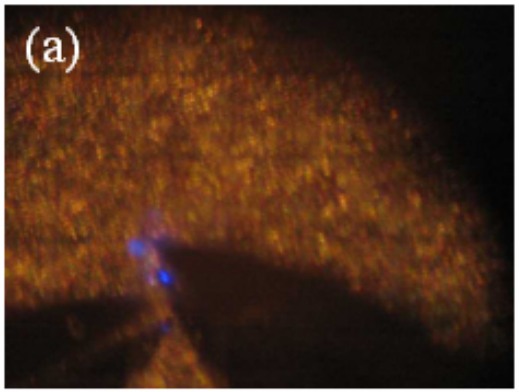


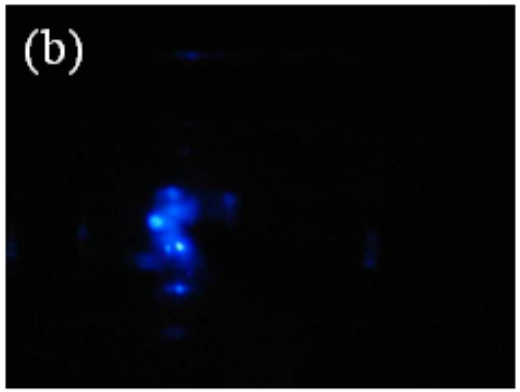
Plane LED

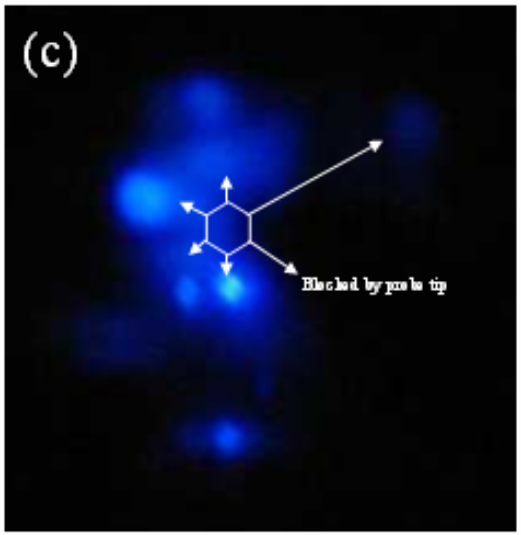


Laser Properties 1 Non-Linearity 2. FWHM 3. Directionality

Laser? How does a laser differ from an LED?







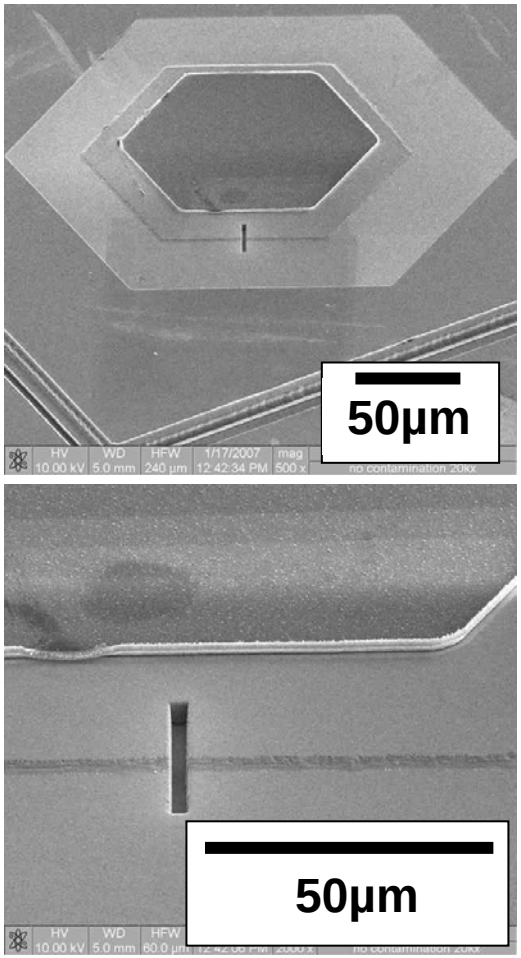
Hexagon Laser

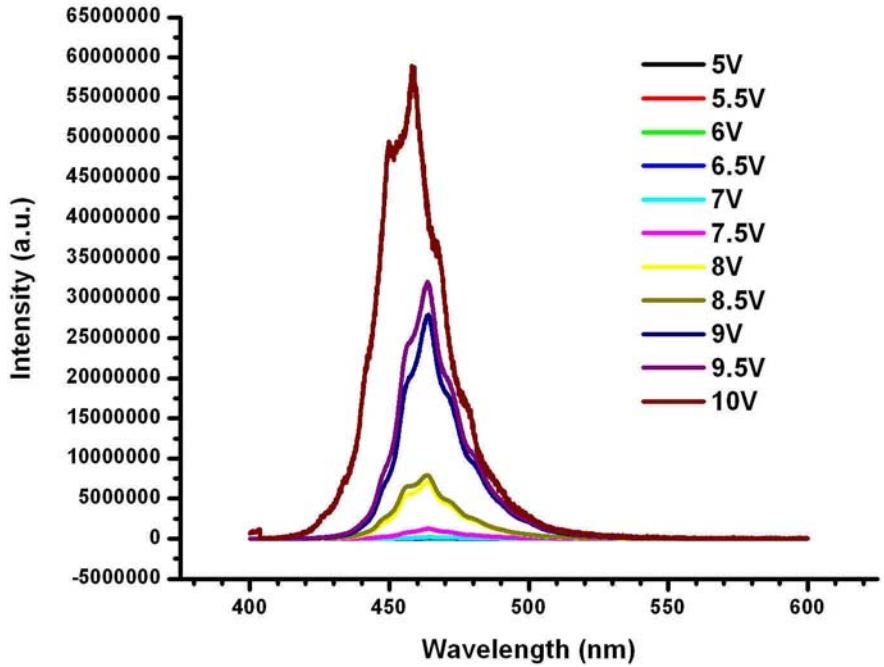
Plane LED

Laser Properties 1 Non-Linearity 2. FWHM 3. Directionality

Is the WGM the origin for the lasing?

- comparison with notched hexagon prism device

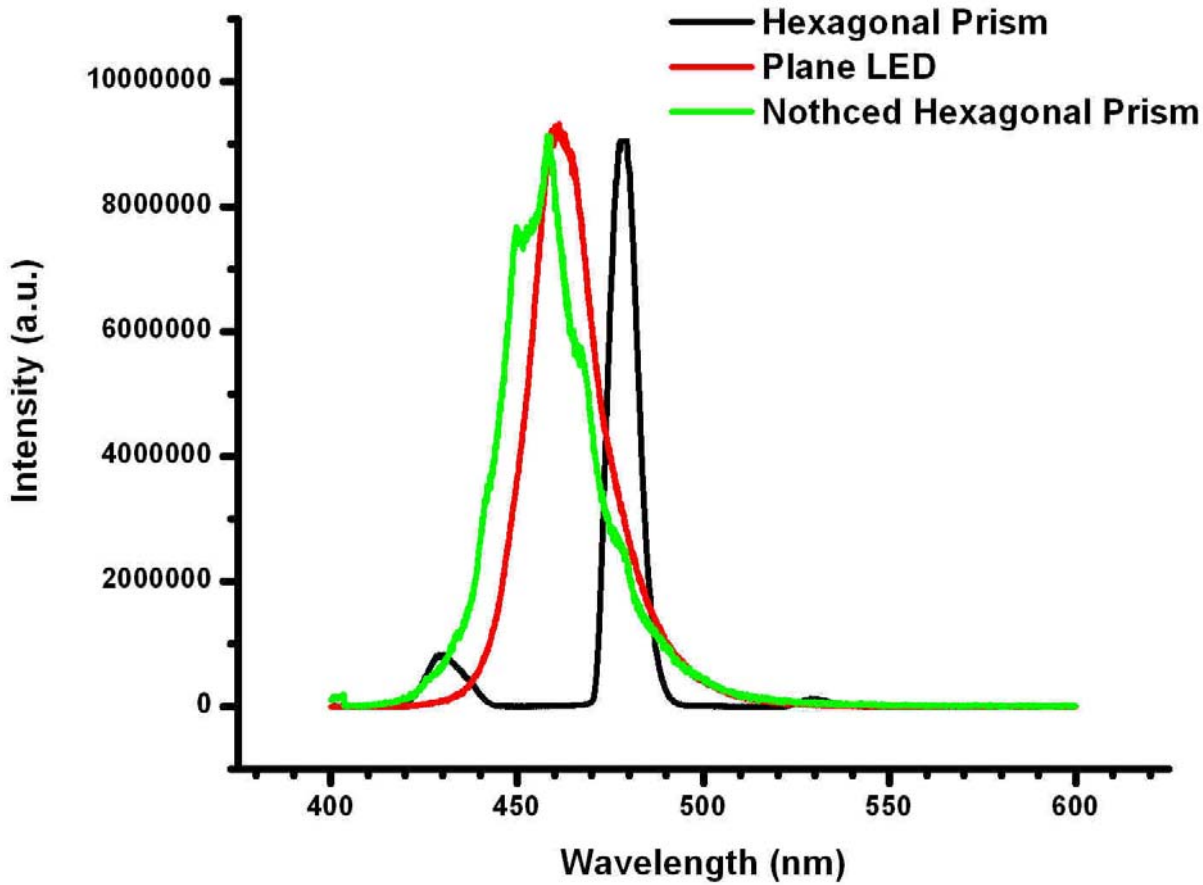




2μm wide, 15μm long, and 5μm deep notch

Lasing Hexagon Prism and Non-lasing planar LED and Notched Hexagon Prism

Three spectrums under 10V bias



Contents

- Current edge-emitting laser and Hexagonal Prism Laser
  - Fundamental mechanism and Limitations

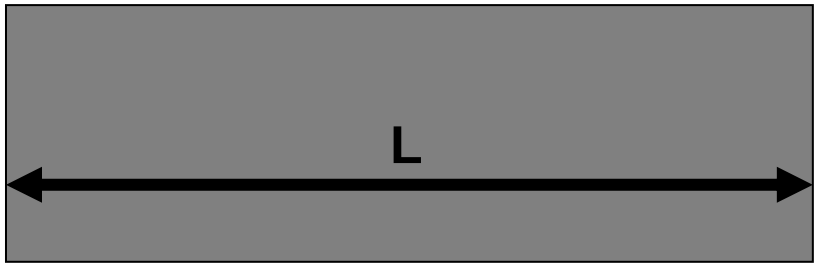
- Characteristics of hexagon prism laser
  - Fabrication Process
  - Threshold (nonlinearity, FWHM shrinkage) and directionality

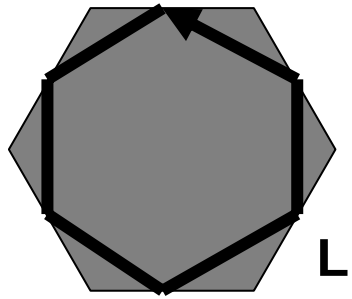
- Advantages and potential applications

Outline

- Current semiconductor laser technology
  - applications
  - laser structures
- Hexagonal prism laser
  - advantages
  - selective epitaxial growth
  - etching process
- Characterization of hexagonal prism laser
  - threshold (nonlinearity, FWHM shrinkage) and directionality
- Advantages and potential applications

Smaller size with equivalent resonance path length: Toward lower threshold power





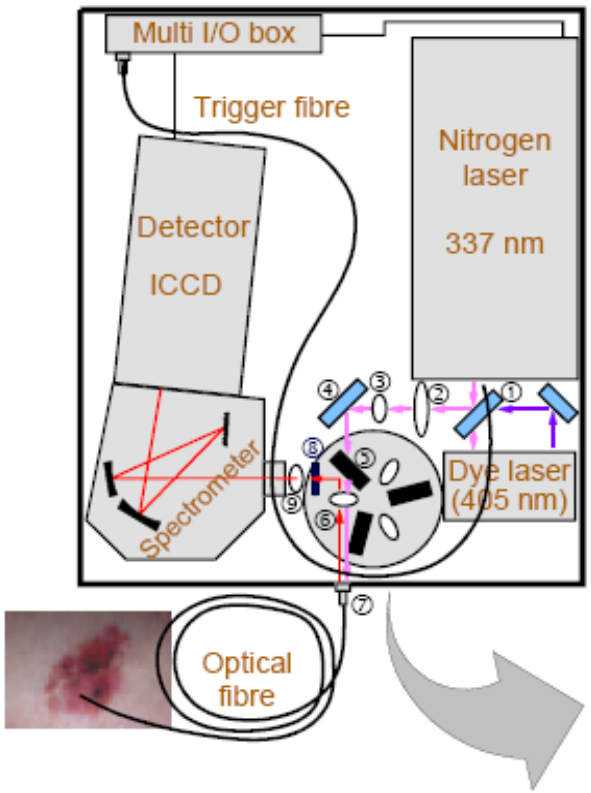
Area saving by factor of

$$1.5\sqrt{3} \approx 2.6$$

	Center wavelength	Threshold current Density (voltage)	substrate
Nichia(1996)	417	4.0kA/cm^2 (34V)	Sapphire
Nichia(1996)	410	8.7kA/cm^2 (11V)	Sapphire
Nichia(1997)	404	4KA/cm^2 (5.5V)	MD-SLS and LOG on Sapphire
Nichia(1998)	394	7kA/cm^2 (6V)	GaN
Sony	411	11.7kA/cm^2 (11.5V)	Sapphire
Fujitsu	408	7.6kA/cm^2 (10.5V)	SiC
Xerox (1999)	401	100mA (6.5V)	Sapphire
NEC	410	10.9kA/cm^2 (10.5V)	GaN
Hexagon Prism	467	7kA/cm^2 (9V)	Sapphire

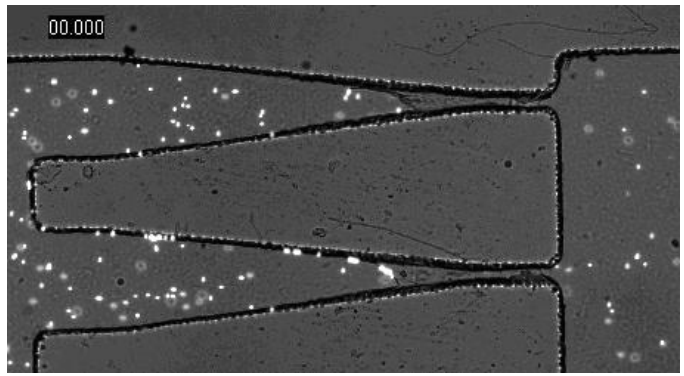
Smaller Laser for Smaller Molecular Detection System

- LIF (laser induced fluorescence)



LIF system for molecular detection
www.oriel.com

- Fluorescence microscopy



Fluorescent tracer particles in micro channel
http://www.chbmeng.ohio-state.edu/~fan/research/11_microPIV.html

Conclusion and Discussion

- Characteristics of hexagonal prism laser

- Advantages compared to current laser devices (In-plane laser, VCSEL)

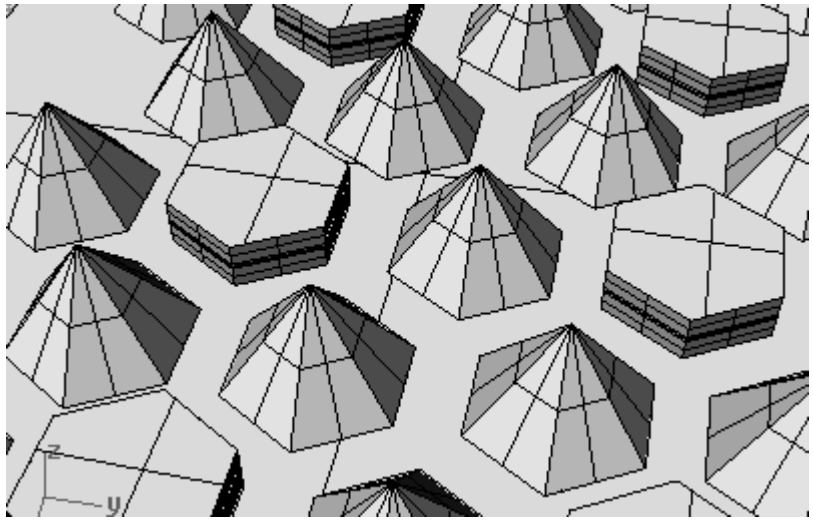
- Potential Applications
  - Smaller size and low threshold
  - Applicable to any other compound materials (As, P)
  - Six fan-out optoelectronic device

  Especially under SEG growth approach
  - Reflector facets with crystallographic flatness
  - Vertical Emitting array device

Thank you for your attention

Questions & Answers

Vertical Emitting Laser Device?

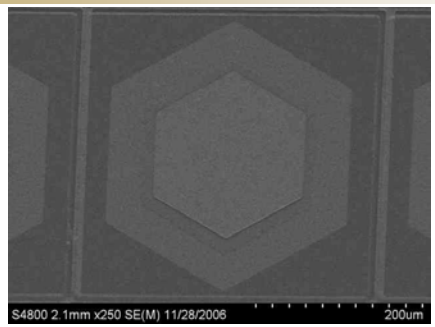


Vertical Emitting array Device

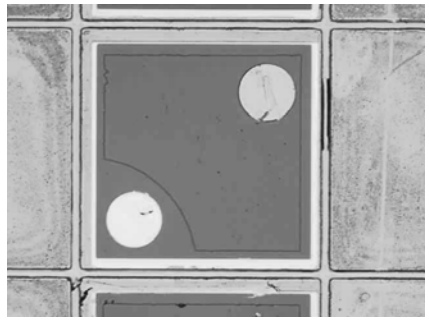
Using
Hexagonal Prisms and Hexagonal Pyramids

Questions & Answers

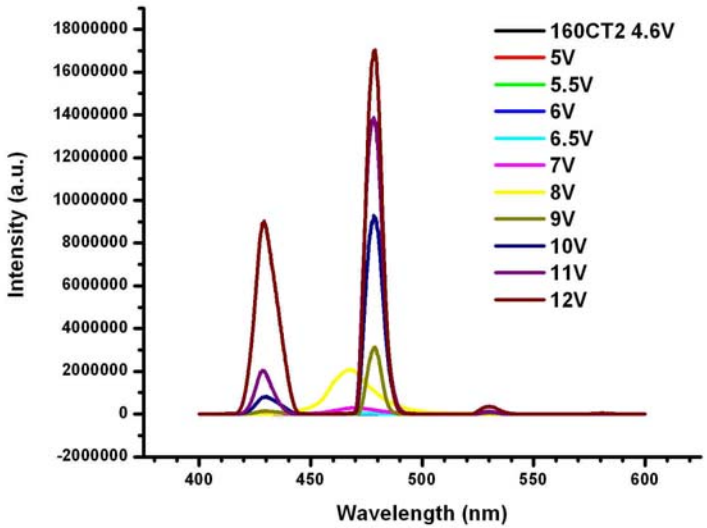
Laser vs. LED

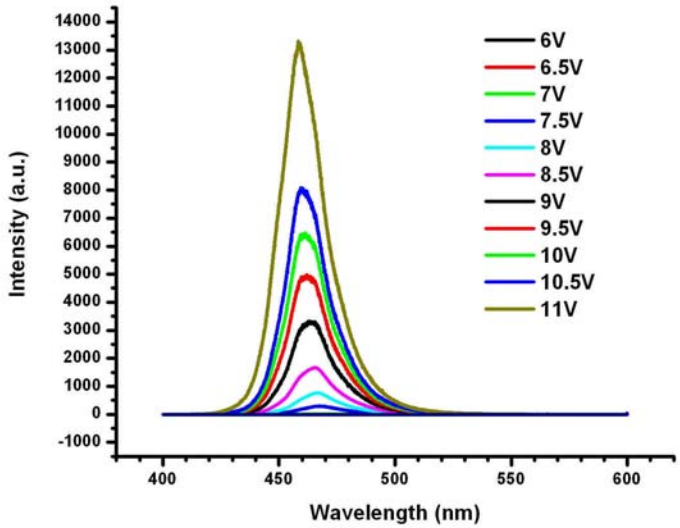


Hexagon Laser



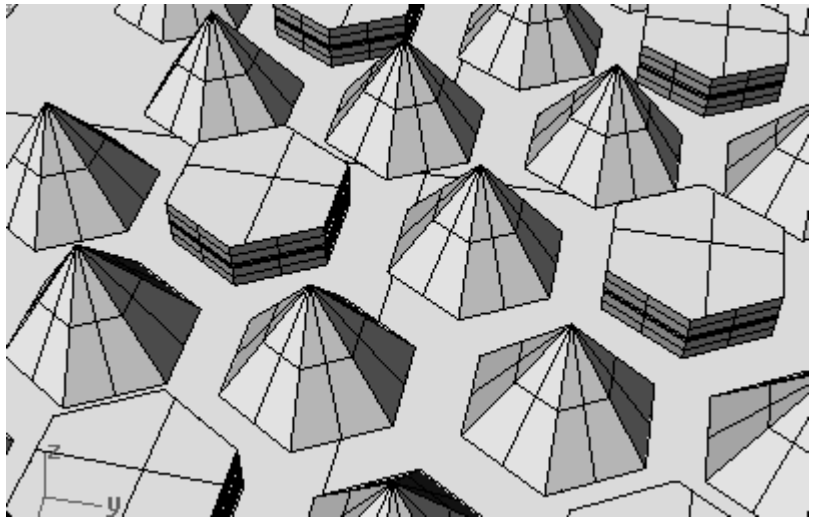
Plane LED





Laser Properties 1 Non-Linearity 2. FWHM 3. Directionality

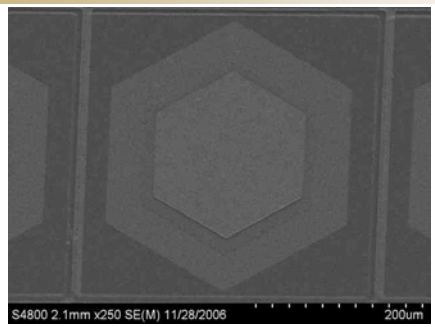
Vertical Emitting Laser Device?



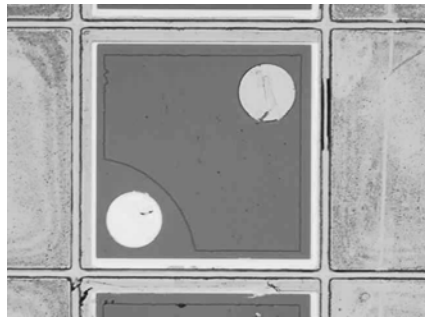
Vertical Emitting array Device

Using
Hexagonal Prisms and Hexagonal Pyramids

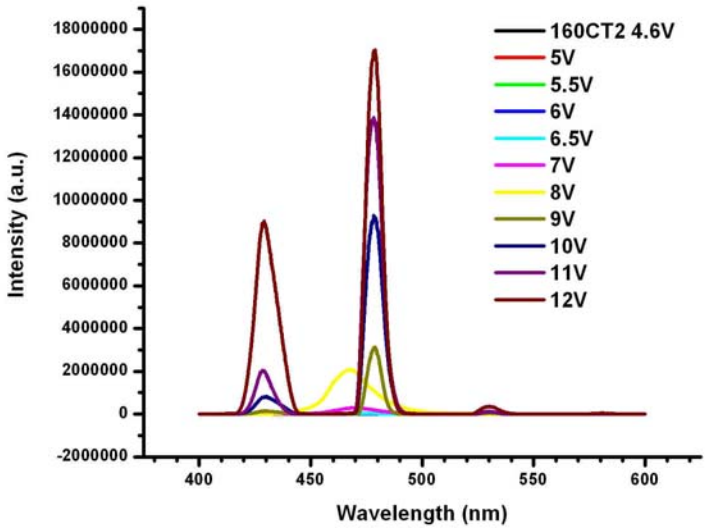
Laser vs. LED

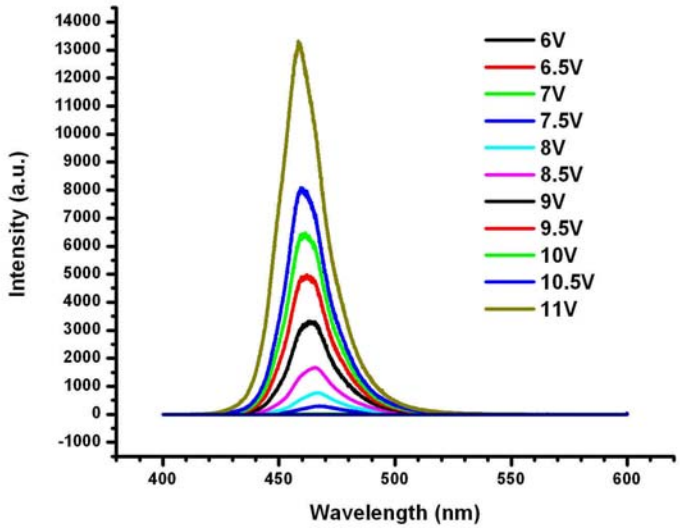


Hexagon Laser



Plane LED





Laser Properties 1 Non-Linearity 2. FWHM 3. Directionality