INDIANHILLS COMMUNITY COLLEGE

Indian Hills Community College presents the series Basics of Photonics Fundamentals (lasers & optics)

FRANK REED
frank.reed@indianhills.edu
641.777.3538

"This material is based upon work supported by the National Science Foundation under Grant No. 1800935.“ "Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation."

Life. Changing.

WELCOME & THANK YOU FOR YOUR INTEREST

Greetings

- I am Frank Reed, Indian Hills's Grant Director & Principal Investigator for the *Developing Photonics Education in Iowa's Rural Secondary Schools* National Science Foundation Grant.
- I have been in the photonics (**lasers and optics**) field since 1989 when I graduated from Indian Hills and have been with IHCC since 1996.
- I do hope you enjoy and learn from these presentations.

- The presentations will cover the following.
  1. Motivation, Light and the Nature & Properties of Light
  2. Optical Components
  3. Basic Laser Safety
  4. Geometrical (RAY) Optics
  5. Physical (WAVE) Optics
  6. **Principles of Lasers**

Motivation

- Currently the U.S. laser & optics industry is growing by leaps and bounds,
  - Or as we like to say “at the speed of light”.
- The medical/bio-science area is the fastest growing followed closely by manufacturing.
  - These two areas will impact each of us on a personal basis.
- Nationally, there are ~2000 entry level photonics technician positions per year with ~20% filled.
- IHCC’s Laser & Optics 2020 graduates received an average starting salary of $61,800.00.
- To increase the number of these technicians, WE must market lasers & optics to our students.
- 70% of technicians working in U.S. photonics industry say that their jobs are intellectually challenging and have no worries about joblessness.
- IHCC’s NSF ATE Grant has the main objective of increasing the number of Photonics Techs in the U.S.
- One way to do that is to introduce teachers to the world of photonics.
  - Therefore, this opportunity is provided for you to learn more about lasers & optics with hope that you will include it in your course work.

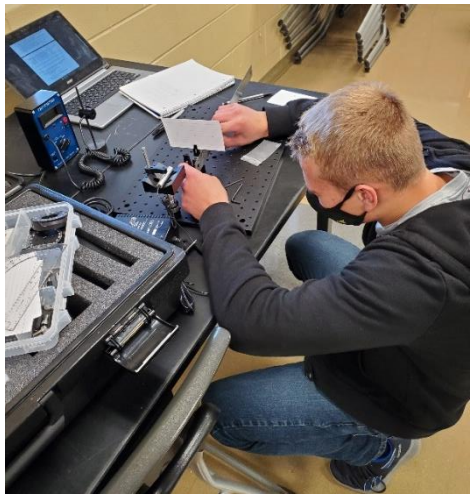
Motivation

Albia High School

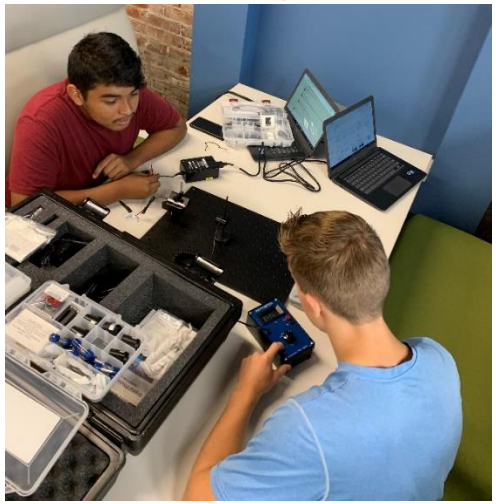
Centerville High School

Davis County High School

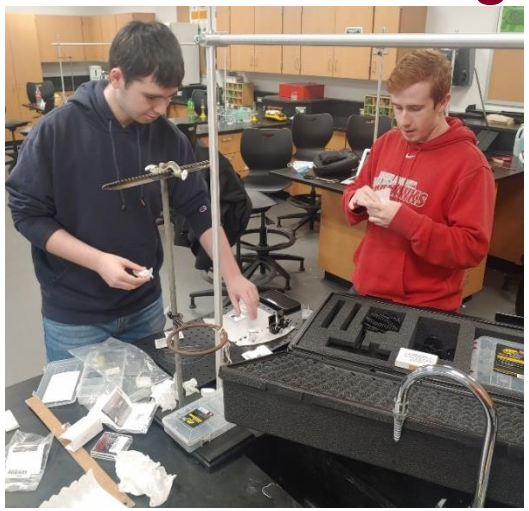
Hybrid (online & hands-on) High School Photonics Training



Davis County High School



Ottumwa High School



North Mahaska High School

Basic Principles of Lasers

- Four Basic Elements of a L.A.S.E.R.
- Population Inversion, Stimulated Emission & Gain
- Properties Related to Applications
- Lasers and Applications
- Laser Pumping Sources & Beam Shape
- Laser Beam Profile & TEM mode
- Laser Beam Pulsing
- Common Laser Types

Four Basic Elements of a L.A.S.E.R.

- Light Amplification by Stimulated Emission of Radiation
- 1. Amplifying/Active/Gain Medium
- 2. Excitation Mechanism
- 3. High Reflectivity Mirror (HR)
- 4. Output Coupler (OC)
  - Mirror with less reflectivity than HR & where beam exits
  - HR & OC comprise the Feedback Mechanism or cavity

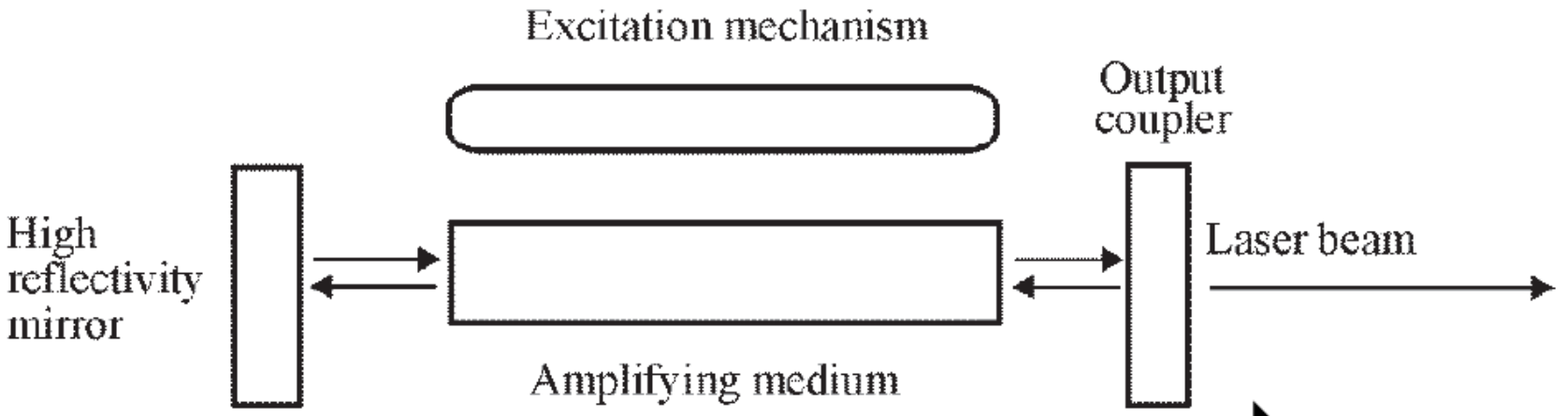
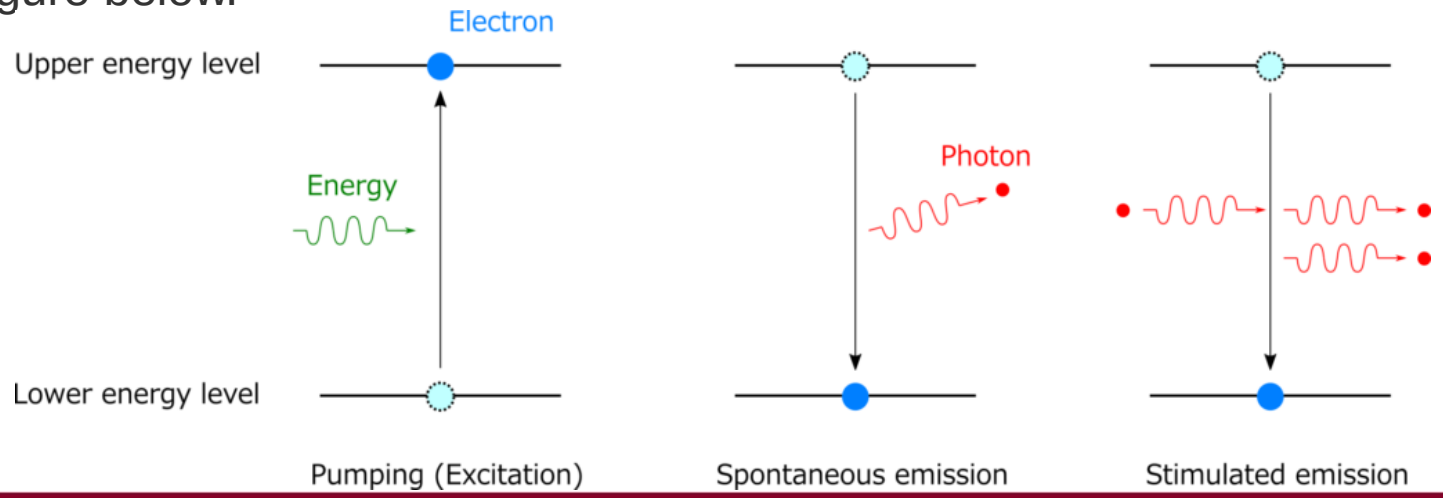


Figure 6-10 *Schematic diagram showing the basic structure of a laser*

Population Inversion

- The process of achieving **more electrons in a higher energy state than a lower energy state**. To achieve this, we need to supply energy (excitation/pumping mechanism) to the laser (active/gain) medium.
- **Stimulated and spontaneous emission**
  - Stimulated emission takes place only when the gain medium is pumped strongly enough creating population inversion, while spontaneous emission happens without population inversion.
- When an optical gain/active medium is energized, an electron is pumped (excited) from a lower energy level to an upper energy level. The excited electron eventually falls to a lower energy level, releasing energy in the form of a photon. Stimulated emission photons have the same characteristics as the photon doing the stimulating. See Figure below.



Properties Related to Applications

Collimation or Least Diverged & Directionality:

- Light where the rays or waves travel in a specific direction and are all parallel
- Used for
  - Reference beams in construction
  - Leveling and grading land
  - Alignment of pipe such as sewer pipe
  - Sending light over long distances without suffering significant divergence
  - Laser pointers
- Determined by
  - Cavity mirror properties including the radii of curvature of the mirrors &
  - Distance between mirrors

Properties Related to Applications

Monochromaticity:

- Single frequency or wavelength or how narrow is the laser beam frequency/bandwidth
- Enhanced by
  - Highly reflecting mirrors
  - Very stable mirror cavity in conjunction with the amplifier by eliminating vibrations
  - Other cavity elements
  - Temperature stability
- Most applications require a single narrow wavelength based on the material absorbing the wavelength

Properties Related to Applications

Coherence:

- Temporal or longitudinal coherence
  - Where ***two/multiple*** coherent waves of equal wavelength stay in phase for a period of time over a certain distance; noted as *coherence length*
- Spatial or transverse coherence
  - Concerns the phase relationship of different parts/points of ***one*** laser beam *across the width* over a period of time and distance; noted as *coherence width*
  - Related to applications in holography

Properties Related to Applications

Intensity or Irradiance:

- Power of the laser beam divided by the cross-sectional area of the beam
- Given in watts per square centimeter (W/cm^2).
- Amount of energy that can be applied within a given amount of time
  - One of the two most important parameters in using the laser for materials (organic or inorganic) processing
- The other important parameter is the laser wavelength per absorption
  - If it cannot be absorbed, it cannot be used for processing

Properties Related to Applications

Divergence:

- Laser beam divergence given in milliradians (mrad)
- Approximate beam divergence (θ) in radians can be obtained by measuring the laser beam diameter (Φ) at two specific, relatively long distance (d_2 & d_1) points from the laser, subtracting the two and dividing it by the distance (L) between the two diameters
  - $\boldsymbol{\theta = \frac{d_2 - d_1}{L}}$
- Beam divergence relates to laser pointing and free space optical communications

Properties Related to Applications

Focusability:

- Smallest diameter that can be obtained with a focused laser is approximately the dimension of the wavelength of the laser
- The diffraction-limited focal spot size of a laser beam depends on its wavelength, the size of the beam at the lens and its M^2 (how round it is) value
- Almost all applications (pointing...not so much) of lasers involve their ability to be focused to a very small spot size

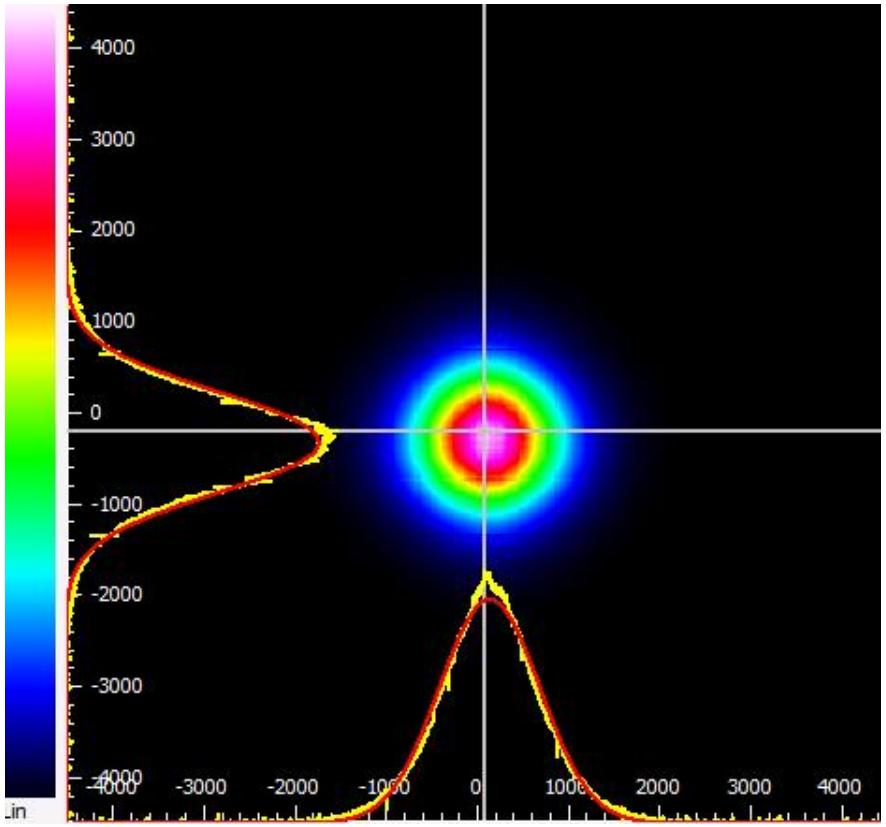
Lasers and Applications

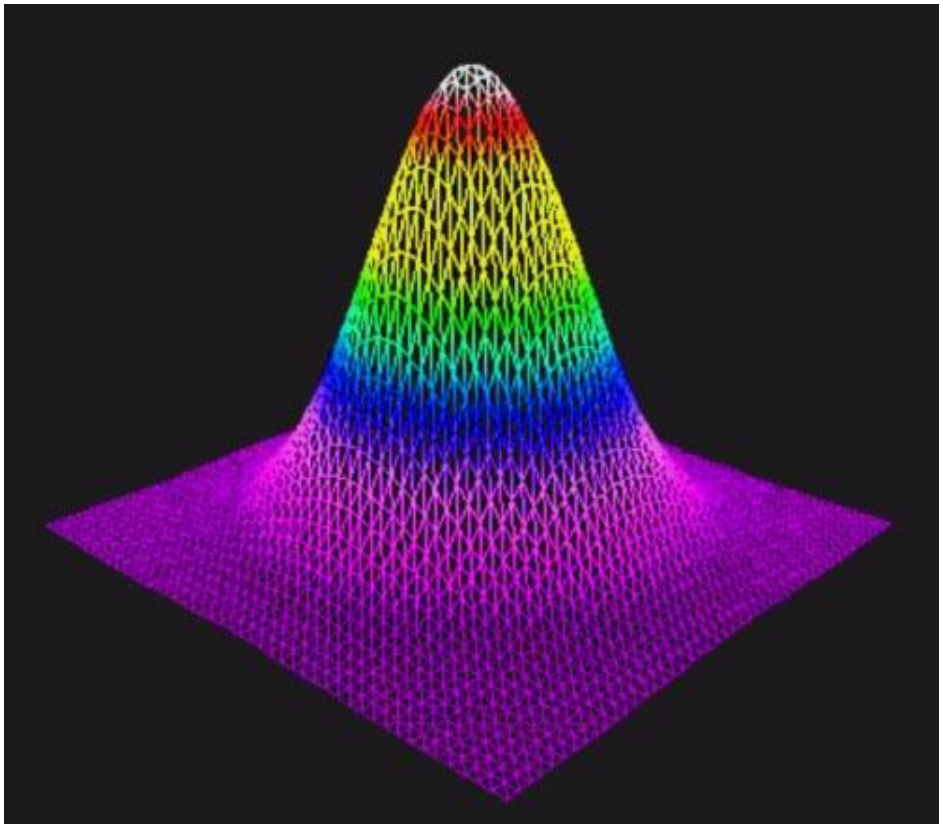
- Sizes ranging from approximately one-tenth the diameter of a human hair (10 microns) to that of 3 football fields
- Powers ranging from nanowatts to a billion trillion watts (10^{21} W)
- Wavelengths or frequencies ranging from the microwave region & infrared to the visible, ultraviolet, & into the soft-X-ray spectral regions
- Generate the very short bursts of light at approximately five million-billionths of a second (5×10^{-15} sec).
- Primary component of some of our most modern communication systems
- Probes that generate the audio signals from our compact disk players
- Cutting, heat treating, cleaning, and removing materials in both the industrial and medical worlds
- Targeting element of laser-guided bombs
- Optical source in both supermarket checkout scanners and tools (steppers) that print microchips.
- To name just a few ☺

Laser Pumping Sources

- **Electron pumping:**
  - Used primarily in gaseous or semiconductor gain media
- **Optical pumping:**
  - Provided by either gas filled flashlamps or other lasers
- **Shape of laser beam per gain-medium and mirrors**
  - Goal is to capture most of the stimulated emission redirecting it into a single path
  - Active/Gain-medium to be of an elongated shape so gain, which is length dependent, will operate primarily in one direction
  - Mirrors are placed at both ends of the medium, forming a cavity/resonator redirecting the beam back and forth through the amplifier thereby allowing the beam to increase to saturation

Laser Beam Profile





A diagram showing a Gaussian (normal distribution) laser beam with a TEM_{00} mode. The TEM_{00} (Transverse Electro Magnetic zero zero) mode is the one most qualified for laser processing.

Laser Beam Pulsing

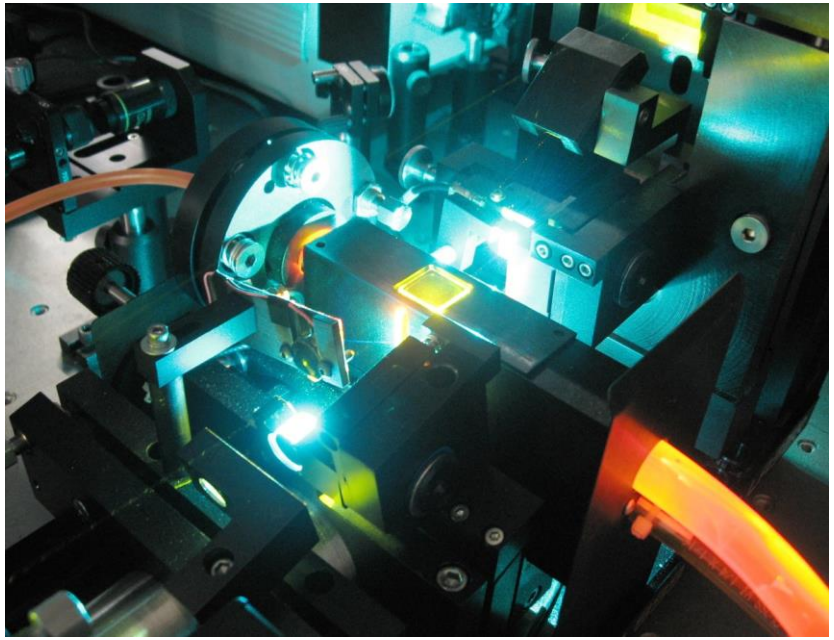
- Continuous Wave (CW)
  - Beam is on all the time
- Pulsing Device
  - Can quickly switch a laser beam between the on/off states.
  - Accomplished with a shutter within the laser cavity/resonator, located between one of the mirrors and the end of the gain medium
    - Shutter can be of various types
  - With the purpose of switching the laser to generate short, intense pulses, where the pulse duration is typically in the nanosecond (10^{-9}) range.

Common Laser Types

- **Gas Lasers**
  - Population inversion is typically achieved by applying a voltage across a glass or ceramic tube that contains the gain medium which is either a low-pressure gas or gas mixture. Shown is a typical Helium Neon gas laser.

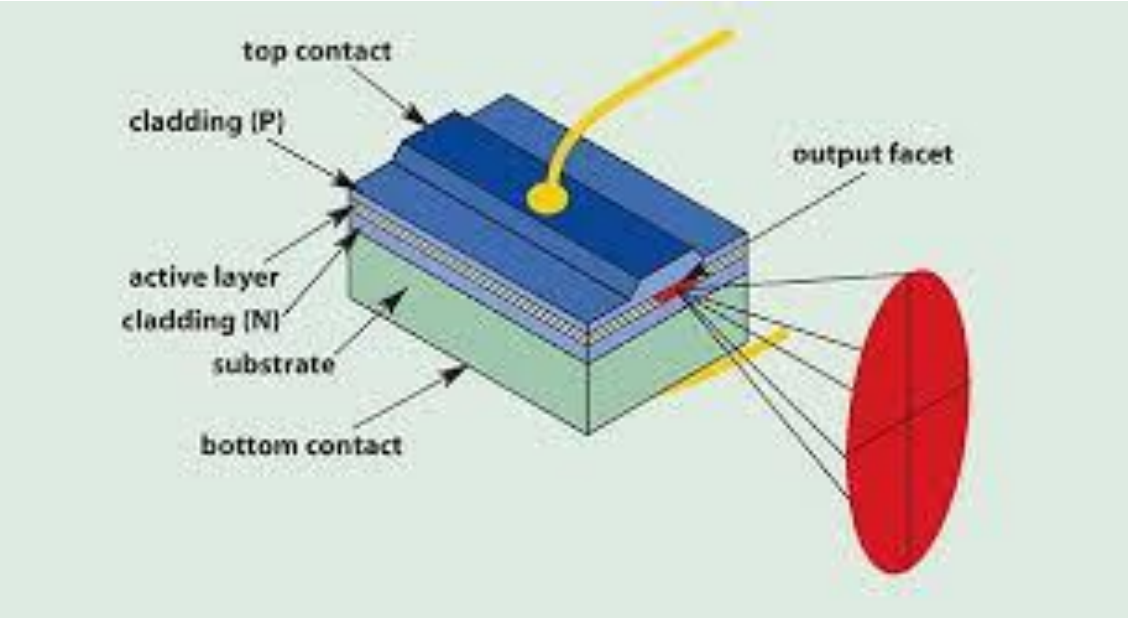
Common Laser Types

- **Liquid or Dye Lasers**
  - Certain organic dye molecules can act as radiating species for lasing since they have sufficiently long lifetimes in their upper energy levels and can therefore radiate energy from that level instead of losing energy due to collisions. The system is known as a liquid dye laser (yellow tube) which are optically pumped by either flashlamps or other lasers.



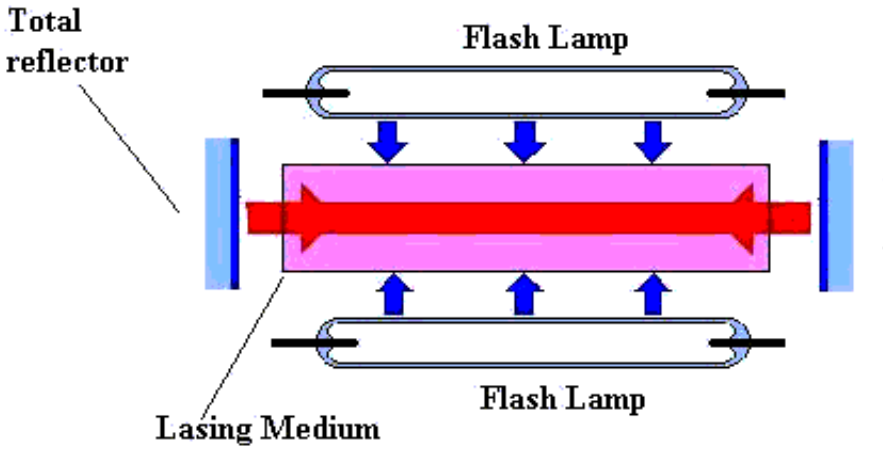
Common Laser Types

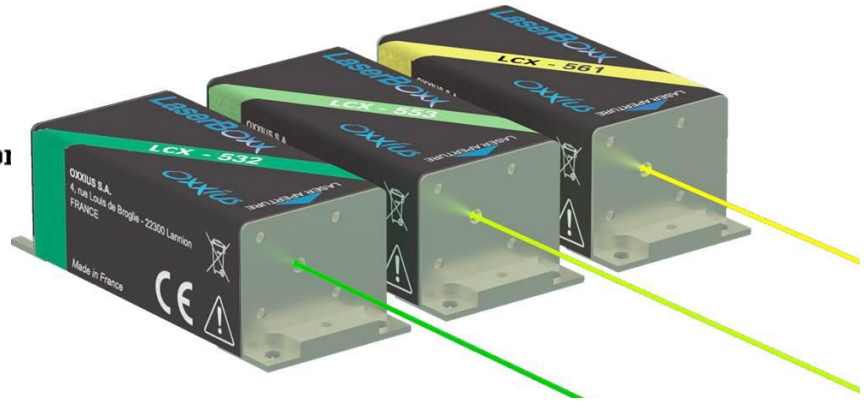
- **Semiconductor Lasers**
  - Often referred to as a laser diode since it operates like a diode with current flowing in the forward direction of the junction. By injecting charge carriers into the region of space defined by the junction, recombination radiation can occur.



Common Laser Types

- **Solid-State Lasers**
  - Refers to a laser whose gain medium has an active ion species introduced as impurities in an optically transparent host material. Most common is the Neodymium Yttrium Aluminum Garnet (Nd:YAG) laser. Nd is the impurity. YAG is the host material.





INDIANHILLS

"This material is based upon work supported by the National Science Foundation under Grant No. 1800935.“ "Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation."

www.indianhills.edu