Semiconductor Diode laser:

Definition:

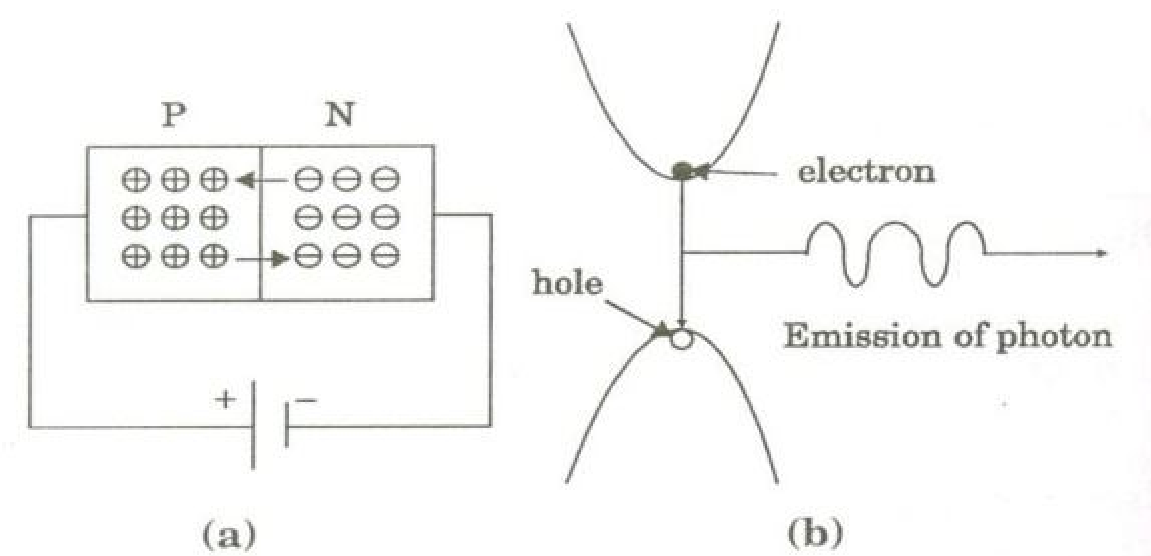
It is specifically fabricated p-n junction diode. This diode emits laser light when it is forward biased.

Principle:

When a p-n junction diode is forward biased, the electrons from n – region and the holes from the p- region cross the junction and recombine with each other.

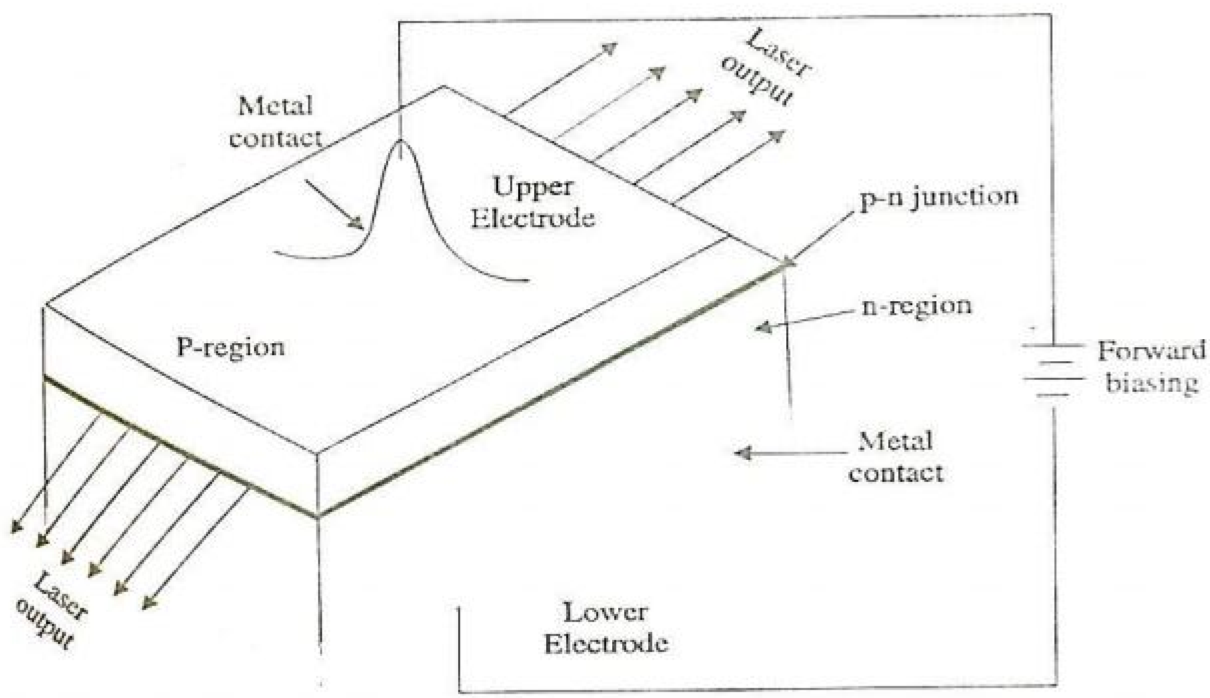
During the recombination process, the light radiation (photons) is released from a certain specified direct band gap semiconductors like Ga-As. This light radiation is known as recombination radiation.

The photon emitted during recombination stimulates other electrons and holes to recombine. As a result, stimulated emission takes place which produces laser.



Construction:

Figure shows the basic construction of semiconductor laser. The active medium is a p-n junction diode made from the single crystal of gallium arsenide. This crystal is cut in the form of a platter having thickness of 0.5μmm.



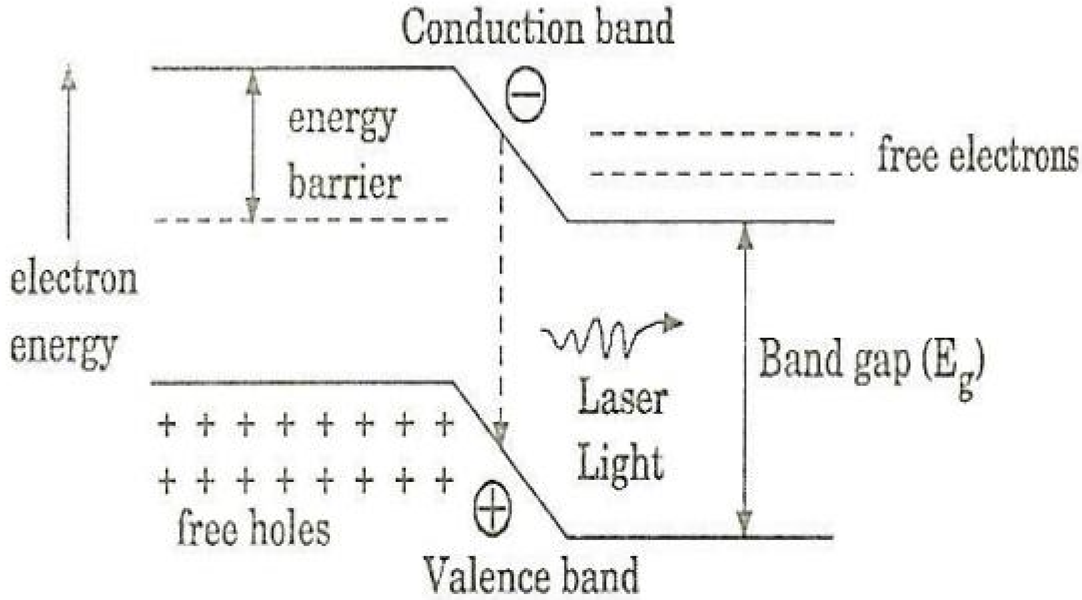
The platelet consists of two parts having an electron conductivity (n-type) and hole conductivity (p-type).

The photon emission is stimulated in a very thin layer of PN junction (in order of few microns). The electrical voltage is applied to the crystal through the electrode fixed on the upper surface.

The end faces of the junction diode are well polished and parallel to each other. They act as an optical resonator through which the emitted light comes out.

Working:

Figure shows the energy level diagram of semiconductor laser.



When the PN junction is forward biased with large applied voltage, the electrons and holes are injected into junction region in considerable concentration

The region around the junction contains a large amount of electrons in the conduction band and a large amount of holes in the valence band.

If the population density is high, a condition of population inversion is achieved. The electrons and holes recombine with each other and this recombination's produce radiation in the form of light.

When the forward – biased voltage is increased, more and more light photons are emitted and the light production instantly becomes stronger. These photons will trigger a chain of stimulated recombination resulting in the release of photons in phase.

The photons moving at the plane of the junction travels back and forth by reflection between two sides placed parallel and opposite to each other and grow in strength. After gaining enough strength, it gives out the laser beam of wavelength $8400\,\overset{\circ}{A}$. The wavelength of laser light is given by

$$E_g = h\nu = h\frac{c}{\lambda}$$

$$\lambda = \frac{hc}{E_g}$$

Where E_g is the band gap energy in joule.

Characteristics:

1. **Type**: It is a solid state semiconductor laser.
2. **Active medium**: A PN junction diode made from single crystal of gallium arsenide is used as an active medium.
3. **Pumping method**: The direct conversion method is used for pumping action
4. **Power output:** The power output from this laser is 1mW.
5. **Nature of output:** The nature of output is continuous wave or pulsed output.

6. **Wavelength of Output:** gallium arsenide laser gives infrared radiation in the wavelength 8300 to 8500 $\overset{o}{A}$.

Advantages:

1. It is very small in dimension. The arrangement is simple and compact.
2. It exhibits high efficiency.
3. The laser output can be easily increased by controlling the junction current
4. It is operated with lesser power than ruby and CO_2 laser.
5. It requires very little auxiliary equipment
6. It can have a continuous wave output or pulsed output.

Disadvantages:

1. It is difficult to control the mode pattern and mode structure of laser.

2. The output is usually from 5 degree to 15 degree i.e., laser beam has large divergence.

3. The purity and monochromacity are power than other types of laser

4. Threshold current density is very large ($400A/mm^2$).

5. It has poor coherence and poor stability.

Application:

1. It is widely used in fiber optic communication

2. It is used to heal the wounds by infrared radiation

3. It is also used as a pain killer

4. It is used in laser printers and CD writing and reading.

Introduction

- Why are we here today?
  - Overview of semiconductor laser diodes
  - Answer key questions
  - Learn
- Why do we care?
  - Take away knowledge to our future employers
  - To serve our scientific interests
  - To give me a good grade!

Questions to be Answered

- What is a semiconductor laser diode?
- What does it look like?
- How do they work?
- What are they made of?
- What are their properties?
- What are their uses?
- How much do they cost?
- Where can you get them?

What is a semiconductor laser diode?

- A *semiconductor laser diode* is a device capable of producing a lasing action by applying a potential difference across a modified pn-junction. This modified pn-junction is heavily doped and contained within a cavity thus providing the gain medium for the laser. A feedback circuit is also implemented in order to control the amount of current sent to the laser diode.

What do they look like?

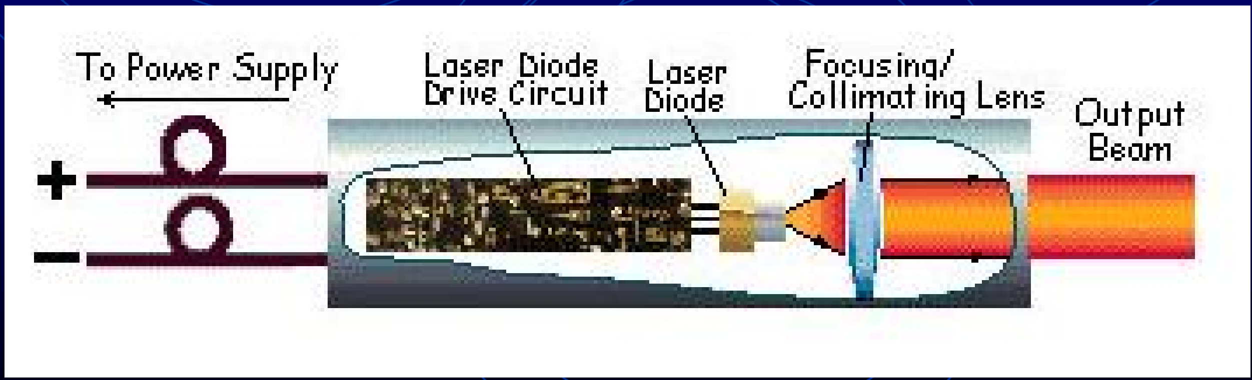
- Semiconductor laser diodes come in many shapes and sizes.
- They maybe round, square, or rectangular, and have a few to many leads.
- There are many reasons for the different shapes including function, power output, specifications, etc.

What do they look like?

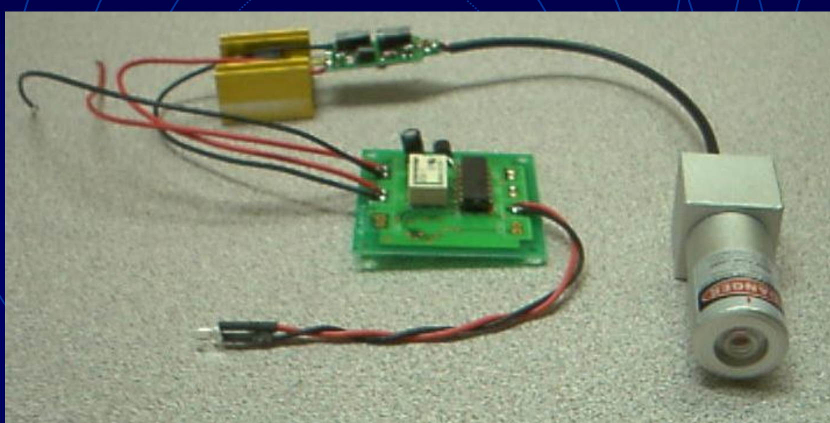
- The above photo shows a variety of low-power semiconductor laser diodes set in several different types of casings.

What do they look like?

- When in use, the S.L.D. is normally mounted in a laser diode module. The S.L.D. is driven and its current controlled by the drive circuit. A lens provides the desired beam shape.



What do they look like?



- The photo below shows a typical module-mounted S.L.D. with driver circuitry.

- The above photo shows a green semiconductor laser diode set in a module and with driver circuitry attached.

What do they look like?

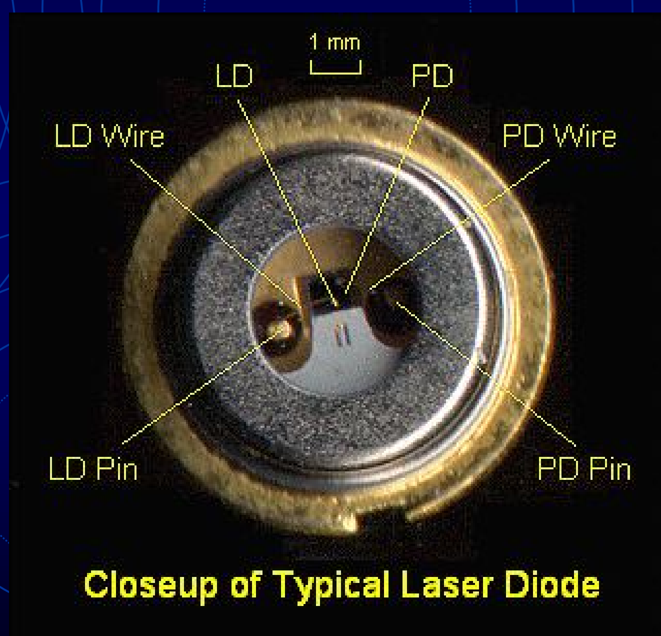
- The left photo shows a high-power semiconductor laser diode set in a module. The middle shows a pigtailed S.L.D. module package for optical communication. The right photo shows a receptacle S.L.D. module package also for optical communication.

What do they look like?

- These S.L.D.s are examples of high-power “bar array diodes”.
- Clockwise from bottom left:
  - 5 element CW array, 150W, actively cooled
  - 60W QCW array, conductively cooled
  - 30W CW array, conductively cooled
  - 2500W QCW stacked array, actively cooled

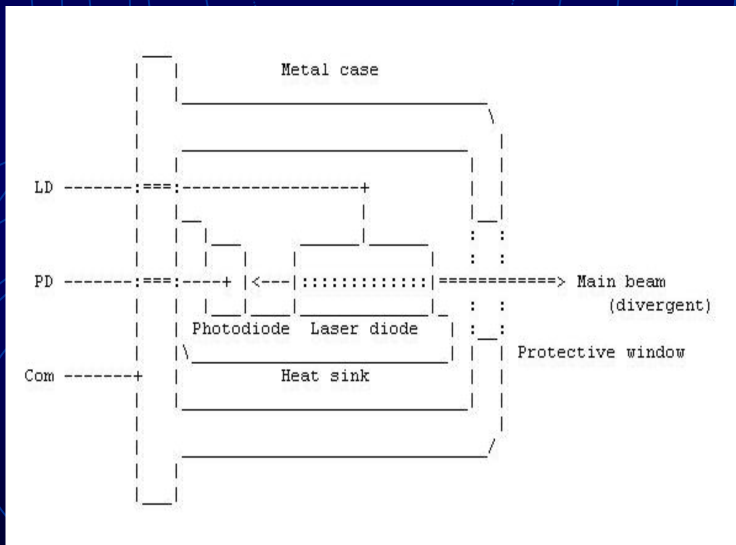
What do they look like?

- This diagram shows a close up view of a typical semiconductor laser diode.
- It can be seen that the S.L.D. consists of a laser diode, a photo diode, and connecting leads and pins.
- All of this is housed in a protective metal casing. A clear screen allows the beam to be emitted.



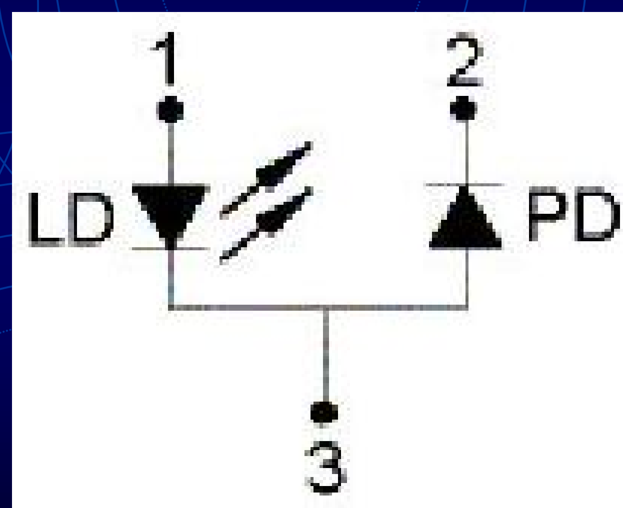
How do they work?

- This diagram shows the inside construction of the semiconductor laser diode.
- It can be seen that the laser diode emits in two directions, sending one as the output, and the other as a feedback to the photo diode.



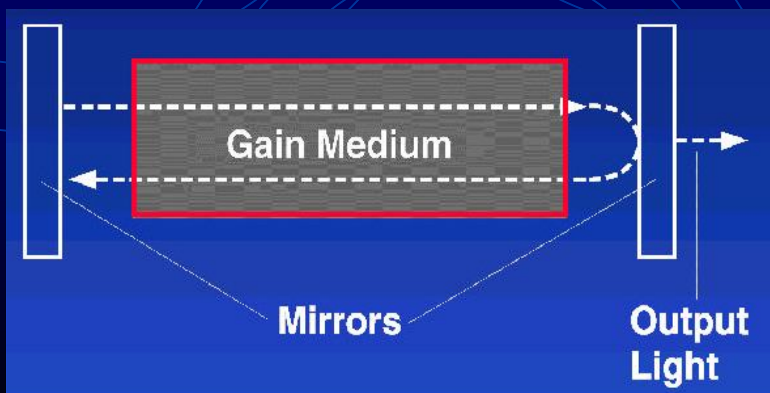
How do they work?

- This diagram shows how the LD and the PD are connected.
- The photo diode optically senses the amount of light sent from the laser diode, this is called feedback.
- This feedback is sent to a drive circuit which regulates the amount of current that the laser diode sees.
- The laser diode is very sensitive, and needs to be operated at 80% of its absolute maximum ratings.



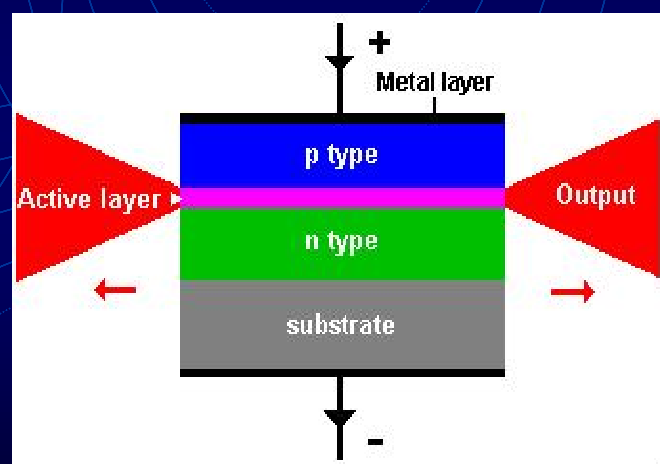
How do they work?

- A typical laser consists of three things:
  - a Pump, a Gain Medium, and a Cavity.
- The diagram below shows the gain medium and the cavity for a generic laser. The pump would send energy into the gain medium and this would excite the electrons and holes within it. This process then gets amplified within the cavity and lasing takes place.

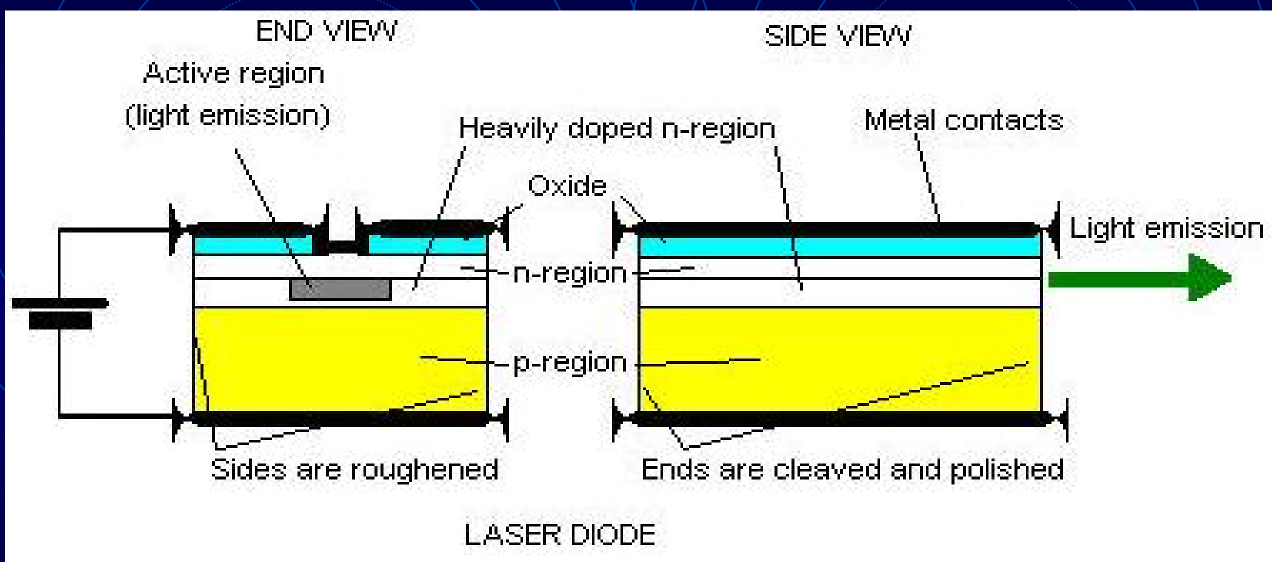


How do they work?

- This diagram shows a cross section of the inside of the laser diode.
- The L.D. consists mainly of a pn-junction separated by a thin active layer.
- The sides of the L.D. form the mirrors of the cavity and the beam is sent in the two opposite directions.
- A potential difference creates the pumping action and starts the lasing process.



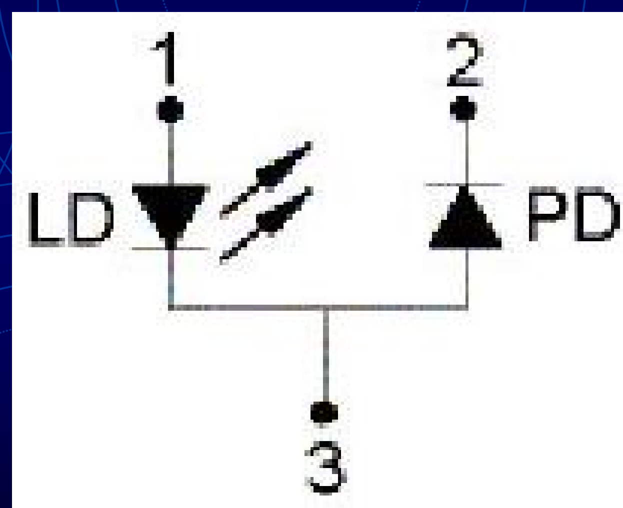
How do they work?



- Here is another look at how the laser diode creates the lasing action. This diagram clearly shows how the cavity is formed by cleaving and polishing the ends and roughening the sides.

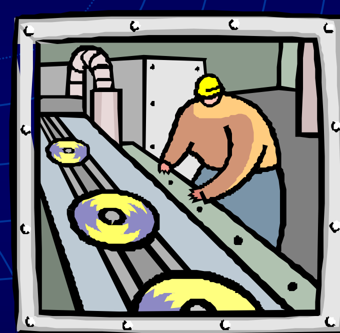
How do they work?

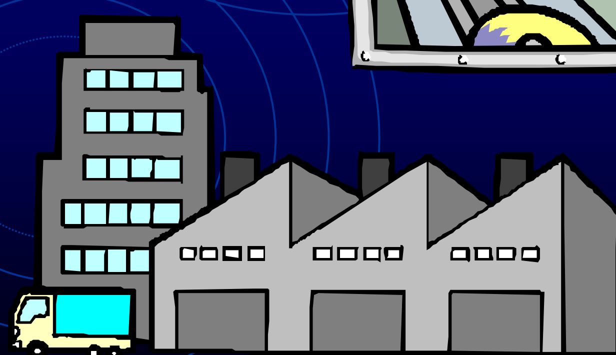
- Now looking back at the schematic of the S.L.D., we can see how the laser diode sends its output to the photo diode.
- The feedback mechanism is the most important feature of the S.L.D., without it, there would be no way to regulate the current and the device would burn itself out very quickly.



What are they made of?

- Semiconductor laser diodes can be made from many different types of semi-conducting materials including several elements found in groups III and V from the periodic table.
- A few examples of these materials include: GaAlAs, AlGaInP, InGaAsP.
- The major reasons for using one material over another are for the specifications needed, especially desired wavelength.



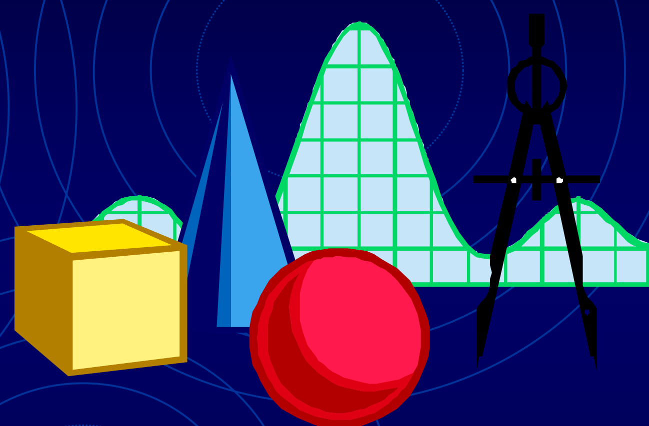


What are their properties?

- The properties of semi-conductor laser diodes can be measured in various ways. The most common terms to describe them are given in the next two slides.
- These properties are used to place S.L.D.s in various classes such as: high/low power, wavelength, high temperature, etc.

What are their properties?

- Here is a list of the most important properties of semiconductor laser diodes.
- S.L.D. properties can be broken up into three general categories: *Electrical*, *Optical*, and *Temperature*.



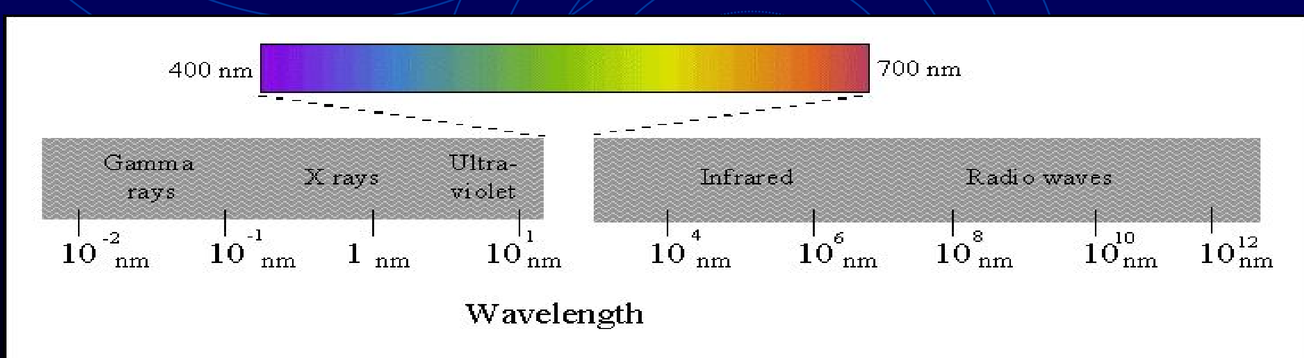
- Electrical:
  - Threshold current
  - Operating current
  - Operating Voltage
- Optical:
  - Light output power
  - Slope efficiency
  - Beam Divergence
  - Peak wavelength
- Temperature:
  - Peak wavelength
  - Laser threshold

What are their properties?

- Electrical:
  - Wall-plug efficiency
  - Duty Cycle
  - Series resistance
- Optical:
  - Continuous/Pulsed Wave
  - Far field pattern
  - Fast axis
  - Slow axis
  - Spectral width
  - Near field pattern
  - Polarization ratio
- Temperature:
  - Active/Conductively cooling
  - Slope efficiency
  - Thermal impedance

What are their properties?

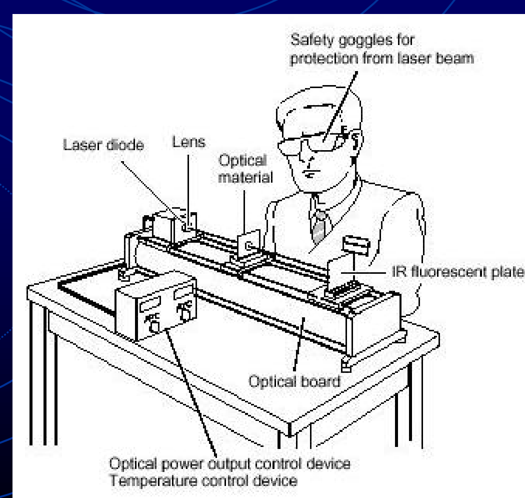
- S.L.D.s can range in wavelengths such as Red (635-670 nm) and IR (780, 800, 900, 1,550 nm, etc). Green (~550 nm), blue (~450 nm), and violet (~400 nm) laser diodes have been produced in various research labs but until recently, only operated at liquid nitrogen temperatures, had very limited life (<100 hours), or both. Recent developments suggest that long lived room temp. green and blue S.L.D.s will be commercially available very soon.



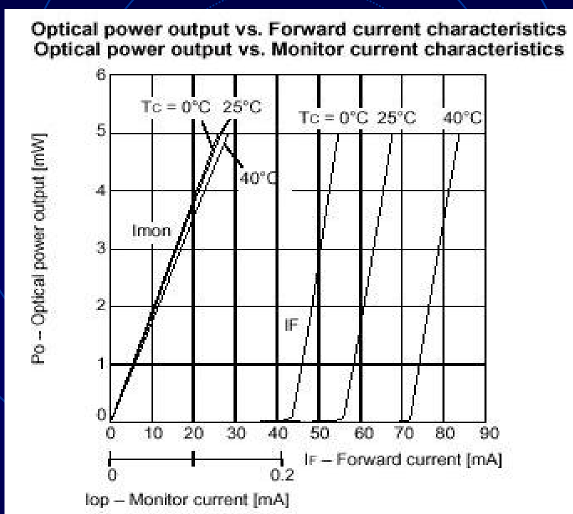
What are their properties?

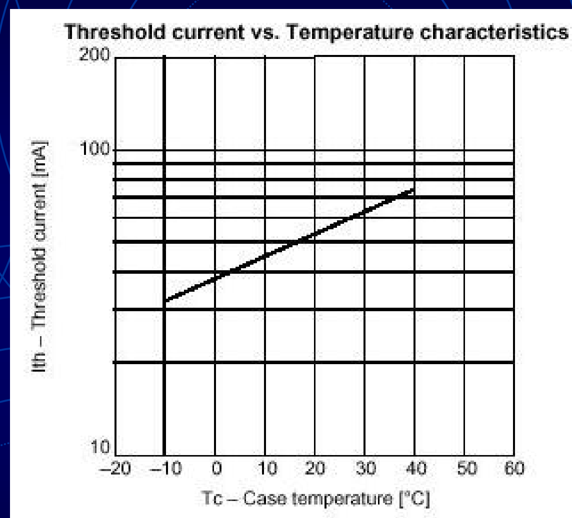
- The beam quality of a semiconductor laser diode can be fair to high quality depending on design. The raw beam is elliptical or wedge shaped and also astigmatic. To make the proper correction requires additional optics (internal or external). Coherence length can be anywhere from a few mm to many meters.

- A typical S.L.D.'s output power ranges from approximately 0.1 mW to 5.0 mW, with up to 100W or more available. The highest power units are composed of arrays of laser diodes, not a single device. As power increases much more temperature and safety considerations are needed.



What are their properties?

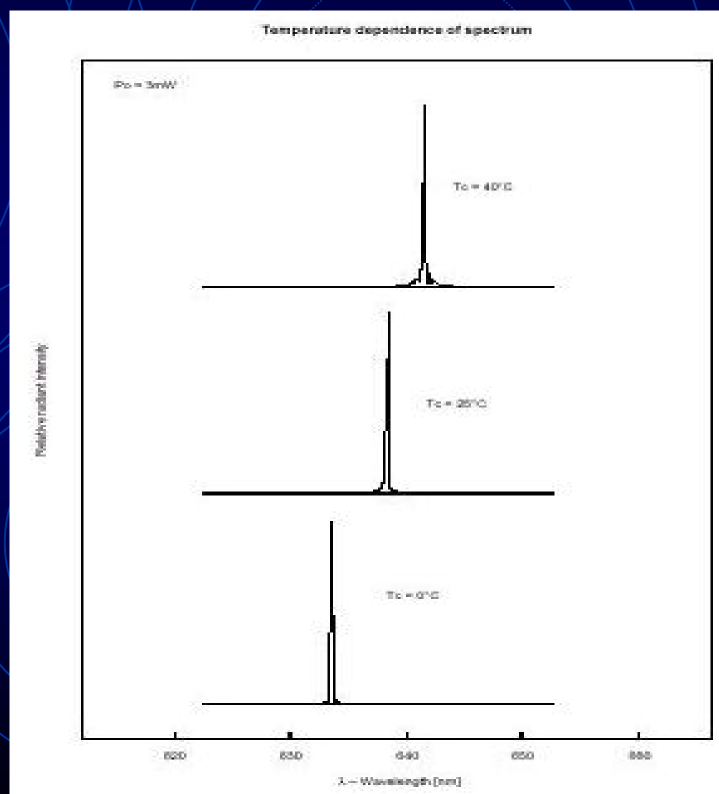




- The graph on the left shows the slope efficiency of a typical low-power S.L.D.
- The graph on the right shows the effect of temperature on the threshold current.

What are their properties?

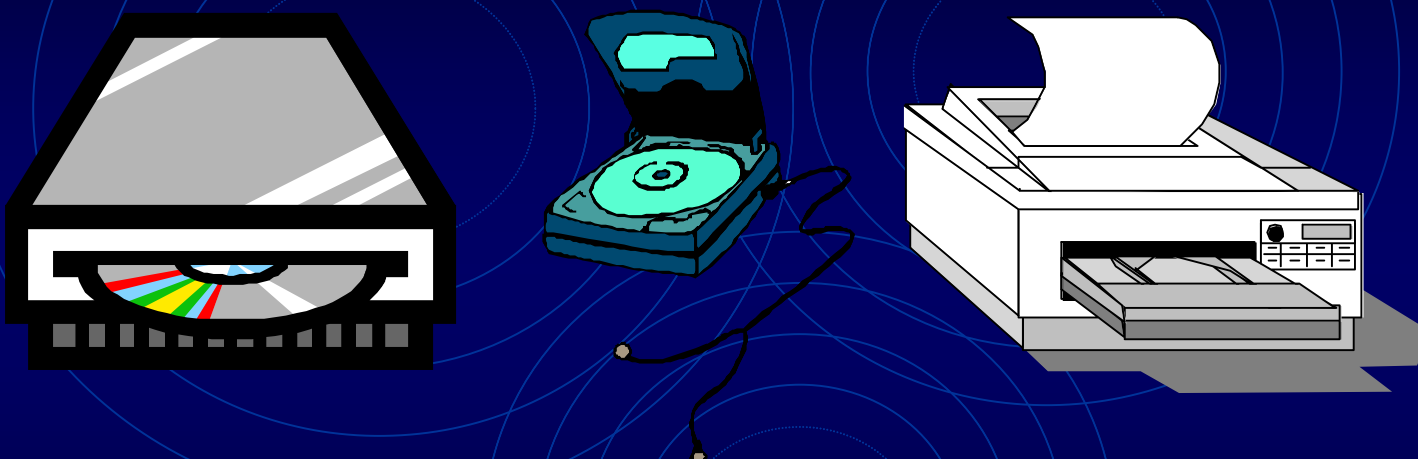
- This graph shows the change in the spectral wavelength due to a change in temperature.
- Temperature also is shown to have an effect on the relative radiant intensity.



What are their uses?

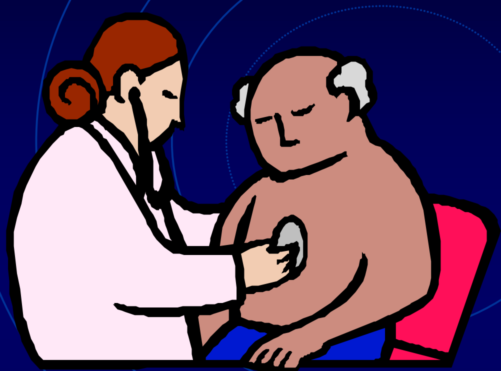
- Semiconductor laser diodes can be used for many applications. The amount of products that can be developed using this simple type of device continues to grow all the time.
- Of course, the most easily thought of product of the S.L.D.s are lasers pointers, but it's what else they can be used for that makes them so special.

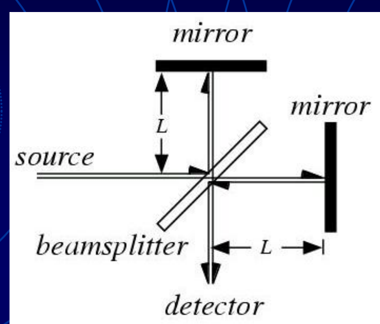
What are their uses?



- Some of the most common uses for semiconductor laser diodes are in everyday devices such as CD ROMs, CD players, LaserDisc and MiniDisc players, and also laser printers and laser fax machines.

What are their uses?





Bar Code Scanner

- Other uses might not seem so easily thought of, such as in medicine, interferometery, and bar code scanners, but are still used by many people everyday.
- S.LD.s can also be used for sighting and alignment scopes, measurement equipment, fiber optic and free space comm. systems, light shows, and as the pumping agent for other types of lasers as well.

How much do they cost?

- Pricing always depends on the features that you include with a product. Semiconductor laser diodes are no different in this respect. Although they probably provide the cheapest form of lasers, they vary greatly in price from cheap to expensive. For a typical low power red S.L.D. you could pay a low as $1, but for a highly scarce blue S.L.D. you could pay as much as $10,000 or more.

Where can you get them?

- There are many business which sell semiconductor laser diodes, a few of which are hyperlinked below.
- Another easy way to get them is to take them out of old CD players and laser pointers.

Closeup of Laser Diode from Sony KSS361A Optical Pickup

- http://www.laser2000.co.uk/index.htm
- http://www.lasermate.com/diodes.htm
- http://www.optima-prec.com/index.htm
- http://www.sel.sony.com/semi/laserdio.htm
- http://www.slicorp.com/main/trade.html
- http://www.laser-diodes.thomson-csf.com/welcome.html.en

Key Points to Remember

- Semiconductor laser diodes are cheap and easy to use compared to other types of lasers.
- They can be used for many applications, and have the ability to be produced in a wide range of wavelengths and powers.
- The most important electronic consideration is the fact that a precisely controlled current source is needed to regulate the amount of current to the laser diode. Without this current protection, the diode will burnout quickly.

In Conclusion

- Semiconductor laser diodes have been around for about forty years now, but their possible uses continue to grow each day. We are at the new dawn of the millennium, and S.L.D.s will help bring about a new revolution in many fields of science; *the new optical solution revolution!*

Bibliography

- Each of the following websites were used in the creation of this presentation:

  - http://hp720.ceg.uiuc.edu/~fabiano/dc98/dc98.html
  - http://opel.ajou.ac.kr/frame1/ldiode.htm
  - http://vcs.abdn.ac.uk/ENGINEERING/lasers/lasers.html
  - http://www.ee.buffalo.edu/~camp/Modules/BarCode/index.html
  - http://www.laser2000.co.uk/index.htm
  - http://www.laser-diodes.thomson-csf.com/
  - http://www.lasermate.com/diodes.htm
  - http://www.misty.com/people/don/laserdon.html
  - http://www.optima-prec.com/index.htm
  - http://www.repairfaq.org/sam/lasersam.htm
  - http://www.sel.sony.com/semi/laserdio.html
  - http://www.slicorp.com/main/trade.html

Semi-conductor Laser

Nd:YAG laser

Nd:YAG laser definition

Neodymium-doped Yttrium Aluminum Garnet (Nd: YAG) laser is a solid state laser in which Nd: YAG is used as a laser medium.

These lasers have many different applications in the medical and scientific field for processes such as Lasik surgery and laser spectroscopy.

Nd: YAG laser is a four-level laser system, which means that the four energy levels are involved in laser action. These lasers operate in both pulsed and continuous mode.

Nd: YAG laser generates laser light commonly in the near-infrared region of the spectrum at 1064 nanometers (nm). It also emits laser light at several different wavelengths including 1440 nm, 1320 nm, 1120 nm, and 940 nm.

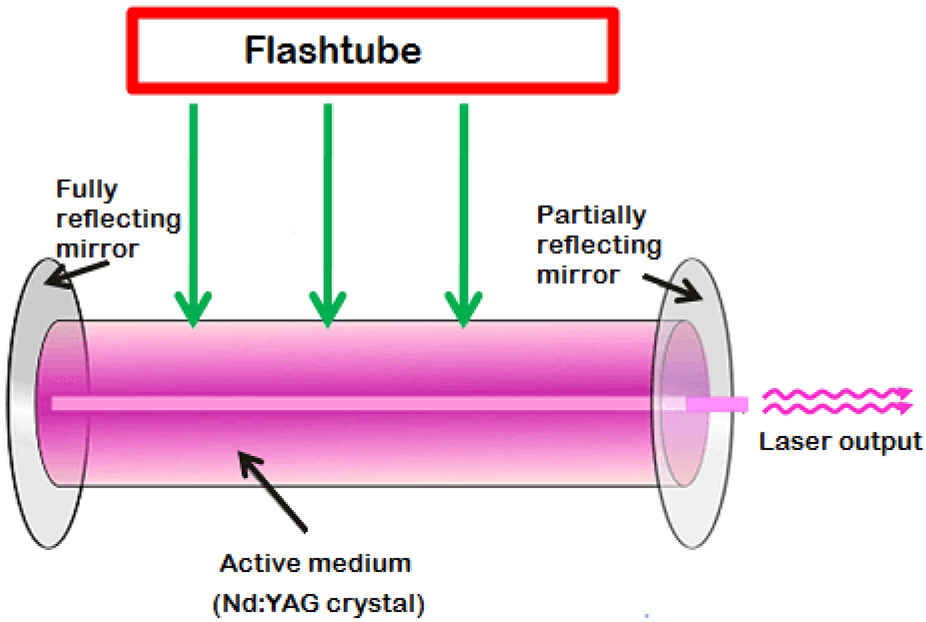
Nd: YAG laser construction

Nd:YAG laser consists of three important elements: an energy source, active medium, and optical resonator.

Energy source

The energy source or pump source supplies energy to the active medium to achieve population inversion. In Nd: YAG laser, light energy sources such as flashtube or laser diodes are used as energy source to supply energy to the active medium.

In the past, flashtubes are mostly used as pump source because of its low cost. However, nowadays, laser diodes are preferred over flashtubes because of its high efficiency and low cost.



Active medium

The active medium or laser medium of the Nd:YAG laser is made up of a synthetic crystalline material (Yttrium Aluminum Garnet (YAG)) doped with a chemical element (neodymium (Nd)). The lower energy state electrons of the neodymium ions are excited to the higher energy state to provide lasing action in the active medium.

Optical resonator

The Nd:YAG crystal is placed between two mirrors. These two mirrors are optically coated or silvered.

Each mirror is silvered or coated differently. One mirror is fully silvered whereas, another mirror is partially silvered. The mirror, which is fully silvered, will completely reflect the light and is known as fully reflecting mirror.

On the other hand, the mirror which is partially silvered will reflect most part of the light but allows a small portion of light through it to produce the laser beam. This mirror is known as a partially reflecting mirror.

Working of Nd:YAG laser

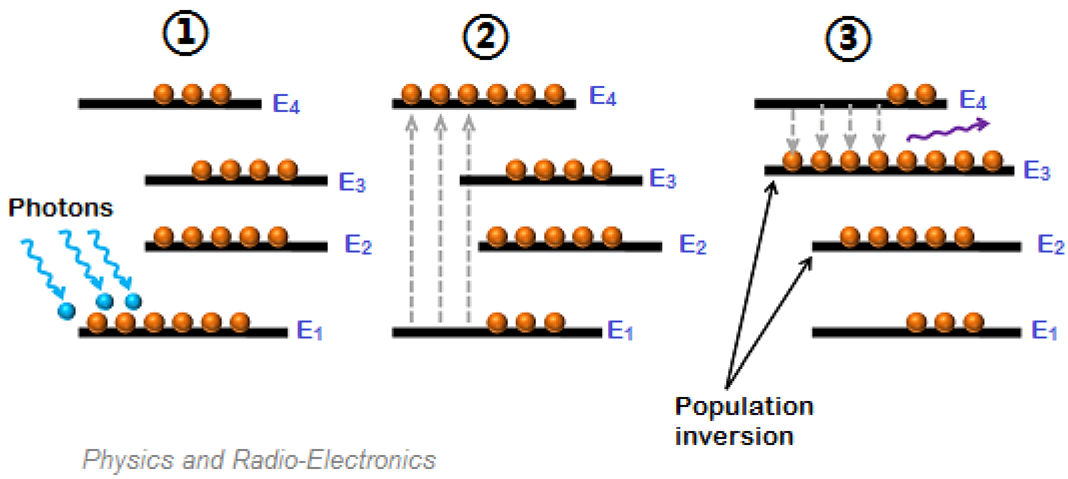
Nd: YAG laser is a four-level laser system, which means that the four energy levels are involved in laser action. The light energy sources such as flashtubes or laser diodes are used to supply energy to the active medium.

In Nd:YAG laser, the lower energy state electrons in the neodymium ions are excited to the higher energy state to achieve population inversion.

Consider a Nd:YAG crystal active medium consisting of four energy levels E_1, E_2, E_3, and E_4 with N number of electrons. The number of electrons in the energy states E1, E_2, E_3, and E_4 will be N_1, N_2, N_3, and N_4.

Let us assume that the energy levels will be $E_1 < E_2 < E_3 < E_4$. The energy level E_1 is known as ground state, E_2 is the next higher energy state or excited state, E_3 is the metastable state or excited state and E_4 is the pump state or excited state. Let us assume that initially, the population will be $N_1 > N_2 > N_3 > N_4$.

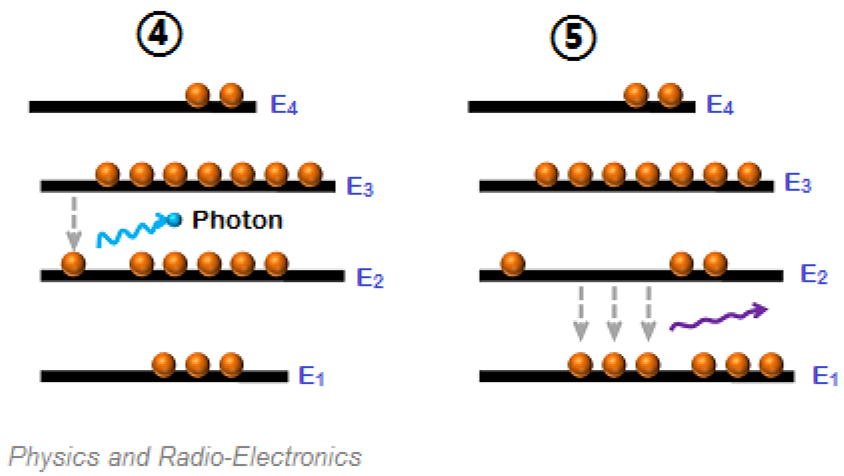
When flashtube or laser diode supplies light energy to the active medium (Nd:YAG crystal), the lower energy state (E_1) electrons in the neodymium ions gains enough energy and moves to the pump state or higher energy state E_4.



The lifetime of pump state or higher energy state E_4 is very small (230 microseconds (Âµs)) so the electrons in the energy state E_4 do not stay for long period. After a short period, the electrons will fall into the next lower energy state or metastable state E_3 by releasing non-radiation energy (releasing energy without emitting photons).

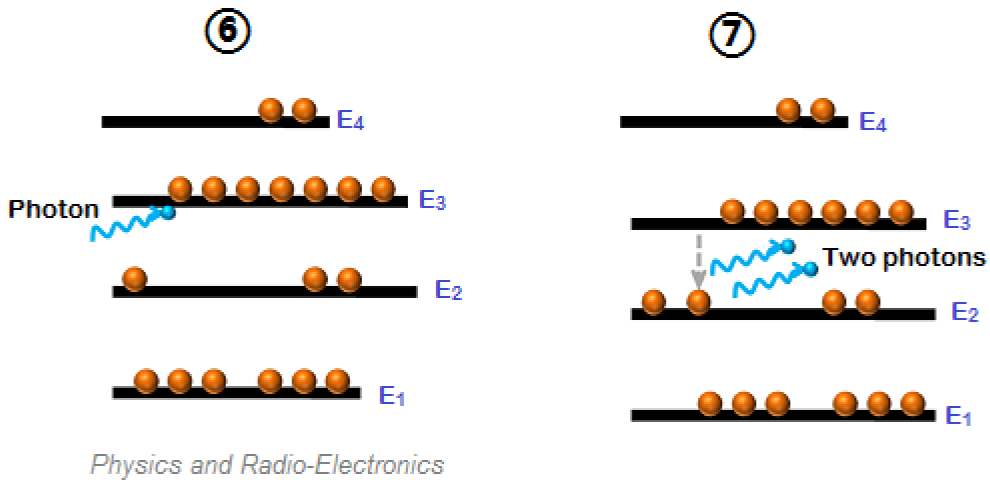
The lifetime of metastable state E_3 is high as compared to the lifetime of pump state E_4. Therefore, the electrons reach E_3 much faster than they leave E_3. This results in an increase in the number of electrons in the metastable E_3 and hence population inversion is achieved.

After some period, the electrons in the metastable state E_3 will fall into the next lower energy state E_2 by releasing photons or light. The emission of photons in this manner is called spontaneous emission.



The lifetime of energy state E_2 is very small just like the energy state E_4. Therefore, after a short period, the electrons in the energy state E_2 will fall back to the ground state E_1 by releasing radiationless energy.

When photon emitted due to spontaneous emission is interacted with the other metastable state electron, it stimulates that electron and makes it fall into the lower energy state by releasing the photon. As a result, two photons are released. The emission of photons in this manner is called stimulated emission of radiation.



When these two photons again interacted with the metastable state electrons, four photons are released. Likewise, millions of photons are emitted. Thus, optical gain is achieved.

Spontaneous emission is a natural process but stimulated emission is not a natural process. To achieve stimulated emission, we need to supply external photons or light to the active medium.

The Nd:YAG active medium generates photons or light due to spontaneous emission. The light or photons generated in the active medium will bounce back and forth between the two mirrors. This stimulates other electrons to fall into the lower energy state by releasing photons or light. Likewise, millions of electrons are stimulated to emit photons.

The light generated within the active medium is reflected many times between the mirrors before it escapes through the partially reflecting mirror.

Advantages of Nd:YAG laser

- Low power consumption
- Nd:YAG laser offers high gain.
- Nd:YAG laser has good thermal properties.
- Nd:YAG laser has good mechanical properties.
- The efficiency of Nd:YAG laser is very high as compared to the ruby laser.

Applications of Nd:YAG laser

Military

Nd:YAG lasers are used in laser designators and laser rangefinders. A laser designator is a laser light source, which is used to target objects for attacking. A laser rangefinder is a rangefinder, which uses a laser light to determine the distance to an object.

Medicine

Nd: YAG lasers are used to correct posterior capsular opacification (a condition that may occur after a cataract surgery).

Nd:YAG lasers are used to remove skin cancers.

Manufacturing

Nd:YAG lasers are used for etching or marking a variety of plastics and metals.

Nd:YAG lasers are used for cutting and welding steel.