Nd-YAG laser

The lasers having the solid material as an active medium is called the solid state lasers.

Generally there are two classes of solid state lasers.

- Continuous Wave Types
- Pulsed Solid State Lasers

The output characteristics of the two are different while the construction and function of all solid state lasers is same.

Nd:YAG (**neodymium-doped yttrium aluminium garnet**; **Nd:$Y_3Al_5O_{12}$**) is a crystal that is used as a lasing medium for solid-state lasers.
The dopant, triply ionized neodymium, Nd^{3+}, typically replaces a small fraction (1%) of the yttrium ions in the host crystal structure of the yttrium aluminium garnet (YAG), since the two ions are of similar size.

It is the neodymium ion which provides the lasing activity in the crystal.

Characteristics of Solid State Lasers

Continuous Wave Type

The term Continuous wave or CW normally indicates that a laser has continuous output. Usually in CW case of laser is continuously pumped.

There are very few solid state crystals that can produce laser light and resist the extreme heat generated by a CW pumping source.

Only common laser of this type is the ND: YAG. Output wave of the Nd: YAG laser is 1.064 microns which is in the near infrared spectrum.

The beam diameter varies from 0.75mm to 6mm while beam profile can be either $TEM_{0,0}$ or multimode.

The $TEM_{0,0}$ beams tend to have narrower beam diameters. Importantly note that the beam divergence from a solid state laser is not constant.

As the laser rod gets heated by the light source during pumping, thermal expansion occurs.

This causes the rod to act as a lens and expand beam. When the rod gets hotter then the rod expands even more and so causing greater divergence.

The beam divergence for the CW solid state laser can be as low as 1 milli radian for TEM0,0 mode lasers are as high as 20 milli radians fro multimode lasers.

The output power for the CW solid state laser varies from a low of 0.4 watt to a high of 600watts.

Since a Q switch can be inserted between the laser mirrors, therefore a very rapidly pulsed output can be obtained.

In addition the CW pumped solid state lasers can be mode locked for the production of ultra short pulses. In fact these lasers can produce a CW, modulated CW, Q switched or mode locked output.

Pulsed Type

The pulsed solid state laser produces a pulsed output due to the pulsing of the input energy.

In pulsed lasers the material used can be cooled between pulses therefore the active medium does not exposed to the extreme temperature rise, experienced by a CW laser.

That is why there are more choices of active media for pulsed laser rather than for CW solid state lasers.

When Nd:YAG is used as a active medium then it can be pulsed very rapidly because it can even with stand the extreme thermal loads of CW operation.

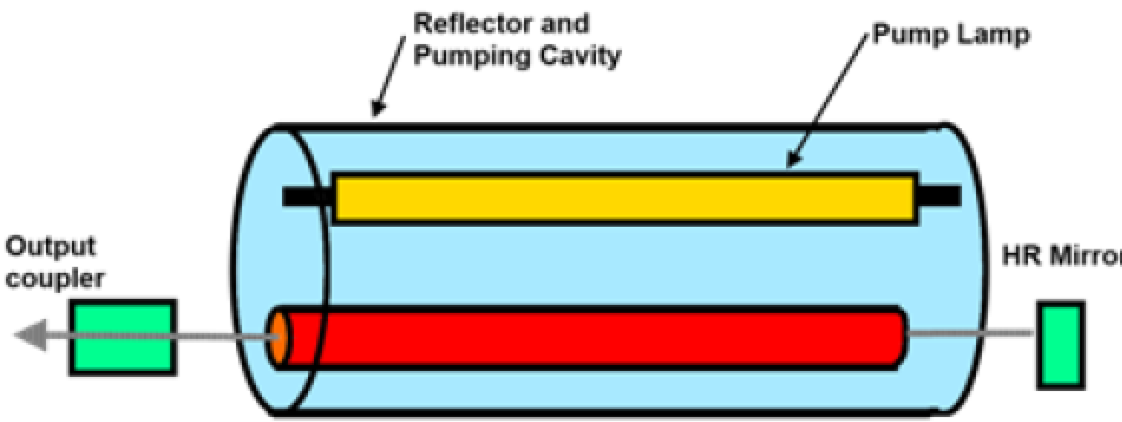
Nd:YAG lasers typically emit light with a wavelength of 1064 nm, in the infrared. However, there are also transitions near 940, 1120, 1320, and 1440 nm.
It is very common to pulse YAG lasers a rate of up to 200 pulses per second. However if ruby or Nd: glass is used as the active medium then pulse rates are limited to 2 or 3 pulses per second.

The additional time between pulses is needed to cool the crystal to prevent fracturing.

Beam diameter of pulsed laser is in 5 to 10mm range. Beam divergence ranges from 1 milli radian to 10 milli radian.

Power output from pulsed laser averages about 400 watts although the peak power of individual pulse is much higher.

Construction of Solid State Lasers



Usually all solid state lasers have similar design.

A laser rod is mounted near an arc or flash lamp.

The lamp is connected to DC power supply that maintains a controlled current through lamp.

The laser rod and lamp are placed parallel to each other and are surrounded by a reflector.

The high reflective (HR) mirror and the output coupler are placed at either ends of the laser cavity.

For simplicity we do not show the DC power supply and cooling system, however they exists in solid state lasers.

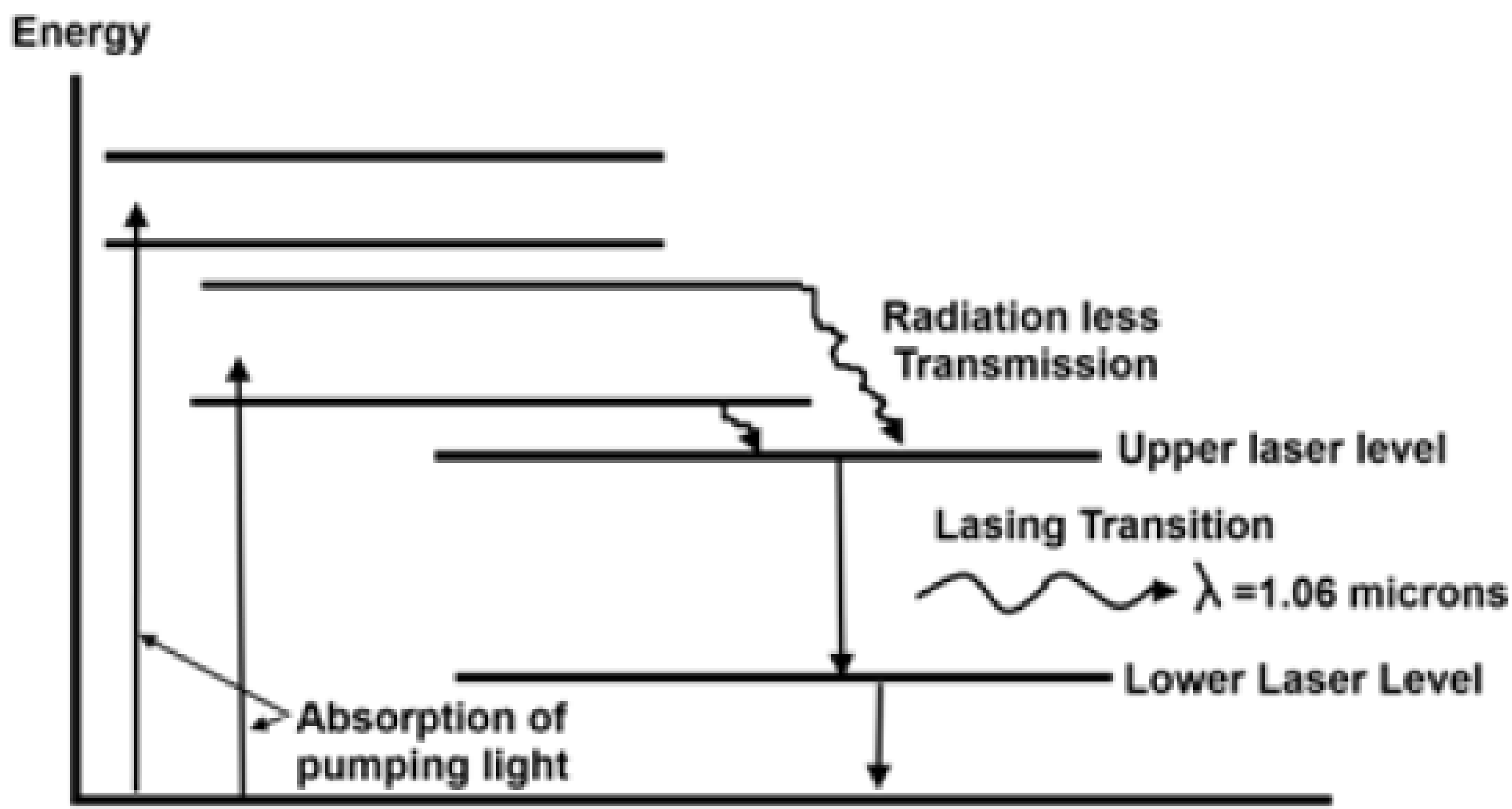
Function of Solid State Lasers

We know that active medium used for solid state lasers is a solid material.

Usually all solid state lasers are pumped optically means light source is used as energy source of solid state lasers.

When the solid material rod absorbs the light energy from light source then becomes excited.

The upper energy level of the ions are radiation less , however when the energy transition takes place then the meta stable upper laser level is soon reached. At this point the emissions occurs which obviously results in lasing.


Energy
Radiation less
Transmission
Upper laser level
Lasing Transition
λ =1.06 microns
Lower Laser Level
Absorption of
pumping light

Applications of Solid state Lasers

Nd: YAG solid state lasers usually used when drilling holes in metals.

Nd: YAG pulsed type solid state lasers can be used in medical applications such as in endoscopy
etc.
As military application, Nd:YAG is used by target destination system.

Advantages of Solid State lasers

The solid state lasers have the following advantages over other types of lasers.

No chance of wasting material in the active medium because here material used is in solid form not in gas form, where this occurs.

Both continuous and pulsed output is possible from solid state lasers.

Solid state lasers have high efficiency compared to some of gas lasers such as HeNe lasers and Argon Lasers.

Efficiency of solid state Nd: YAG laser is 2% to 3%.

Construction of solid state laser is comparatively simple.

Beam diameter of solid state laser is very less than CO_2 lasers.

Output power ranging from very low value of about 0.04 watts to high value of about 600 watts.

Cost of solid state lasers is economical.

Disadvantages of Solid State Lasers

Efficiency of solid state laser is very low as compared to CO_2 lasers.

Great disadvantage of solid state lasers is the divergence, which is not constant and ranges 1 milli radian to 20 milli radian.

Output power is also not very high as in CO_2 lasers.

Due to thermal lasing in solid state lasers, the power loss occurs when the rod gets too hot.

Producing solid state Rods for Lasers

The active medium in solid state lasers can be one of different crystals.

These crystals are not found in nature but rather they are produced commercially such as Ruby, Nd: YAG (Neodymium: Yttrium, Aluminum garnet), Nd: glass (Neodymium: glass), erbium etc.

The crystals used in the lasers are made by doping a highly transparent host material with a metal that will lase.

For example YAG host material that has been heated and is in melton form can be doped with Nd. When the mixture cools, a crystal begins to form.

A cylindrical crystal is then carefully drawn from the melton material when it continues to cool. This process is called growing a crystal.

Once the crystal is completely grown then ends of the cylinder are polished to perfection.
The final result is a Nd: YAG rod, that is used as an active medium in a solid state laser.

Other solid state lasers rods are produced in similar manner.
During the above process that any variation in temperature of the melton material can cause distortion in
the crystal.

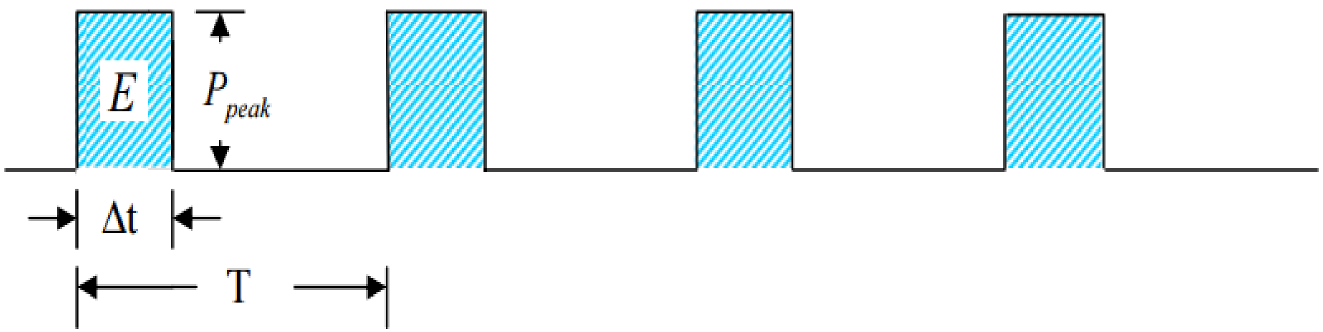
The Nd comprises between 0.7 & 1.25 of the total weight of the Nd: YAG active medium.

It must be evenly distributed throughout the crystal or “hot spots” will appear in crystal. These two can
cause distortion.

Average and Peak Power – A Tutorial

It is easy to calculate the power or energy of optical pulses if the right parameters are known. Presented here are the relationships among some basic quantities often needed when working with laser pulses and power or energy meters.

Consider a regularly repeating train of optical pulses with repetition rate $f = 1/T$ as shown below.



Assume the energy, E , contained in every pulse is constant. Power is just the time rate of change of the energy flow (energy per unit time). So this leads us to define two different types of power.

1. Definition of **peak power**:

Rate of energy flow in every pulse.

2. Definition of **average power**:

Rate of energy flow averaged over one full period (recall that $f = 1/T$).

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   Rate of energy flow in every pulse.

$$P_{peak} = \frac{E}{\Delta t}$$

2. Definition of **average power**:

   Rate of energy flow averaged over one full period (recall that $f = 1/T$).

$$P_{avg} = \frac{E}{T} = Ef$$

Solve both for E and equate:

$$P_{peak}\Delta t = P_{avg}T$$

Rearranging variables allows us to define a new quantity called Duty Cycle, the fractional amount of time the laser is "on" during any given period.

$$\text{Duty Cycle} \equiv \frac{\Delta t}{T} = \frac{P_{avg}}{P_{peak}}$$

Therefore the peak power of a pulse can easily be calculated if the average power and the Duty Cycle are known:

$$P_{peak} = \frac{P_{avg}}{\text{Duty Cycle}}$$

For example, ND-YAG laser might have a 10 ns pulse width, energy of 10 mJ per pulse, and operates at a repetition rate of 10 pulses per second. This laser has a peak power of

$$P_{PEAK} = 10 \text{ mJ} / 10 \text{ ns} = 1 \text{ MW},$$

and average power of:

$$P_{AVG} = 10 \text{ mJ} \times 10 \text{ (1/s)} = 100 \text{ mW}.$$

The pulse length can be very short (i.e. picoseconds or femtoseconds) resulting in very high peak powers with relatively low pulse energy, or can be very long (i.e. milliseconds) resulting in low peak power and high pulse energy.