Light Amplification by Stimulated Emission of Radiation

by

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What is LASER?

LASER is a acronym for Light Amplification by Stimulated Emission of Radiation.
But what does that mean? A LASER is a generator for lightwaves based on atomar and quantumphysical effects. The light emitted by a LASER is more equal to radio waves than to „usual heat sources".
The main differences between those two light sources are the coherence of time and place of the LASER that will be explained in more detail later. The main aspects of LASER light are the hight concentration of energy and the monochromatic light.

The „founders" of LASER

The main principles were first written in 1917 by A. Einstein but the first LASER was built in 1960 by the russians N.S. Basov and A.M. Prokhorov. The theoretical base came from C.H. Townes. 1964 those three physicians got the Nobel Prize for their work.

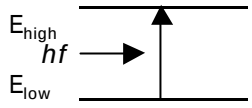
LASER basics

coherence

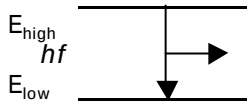
A laser is a device that creates and amplifies a narrow, intense beam of coherent light. Coherent means that the photons emitted by the source are of the same phase and go into the same direction. There is no coherence in the light of heat sources because the electrons that emits the photons are not linked together.

energy levels

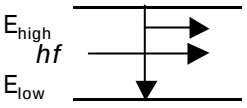
As mentioned before electrons are responsible for the emission of photons. But why? Let's have a look on the different energy levels of a atom.
The energy of a electron depends on its distance from the core and its travelling speed. Electrons that a far away from the atom's core have more energy and core-near electrons have lower energy.
A electron from a high energy level looses energy by dropping down to a lower level. It emits this energy by a photon. Let's say the high energy level is called E_{high} and the low energy E_{low}. With this definition a falling electron emits a photon with the energy $hf=E_{high}-E_{low}$. Vice-verca by giving this energy to a electron you can push it from E_{low} to E_{high}.
The first case is called spontaneously emission and the second case is called absorption. Spontaneously means without any outer influence. But there is also the possibility to force a electron on a high level to emit a photon by shooting at it with a existing photon. This is called a stimulated emission. Those photons have the same energy the same direction and the same phase like the controlling photon – they are coherent.



A photon a pushing a electron to a high energy level



The electron drops back to a low energy level



The stimulated emission creates a new photon

This stimulated emission of coherent photons is the main fact of LASER light and of course the reason for the acronym.

materials and function

The most important materials for building a LASER are liquids, crystals, gas or semi-conductors. But the main differences do not depend on the used material but on the method how the electrons are forced to go to a higher energy level.
Fluid or crystal LASERs will receive photons from another light source. This action is called optical pumping. Semi-conductor LASERs will be messed up with high energetic atoms.

optical resonators

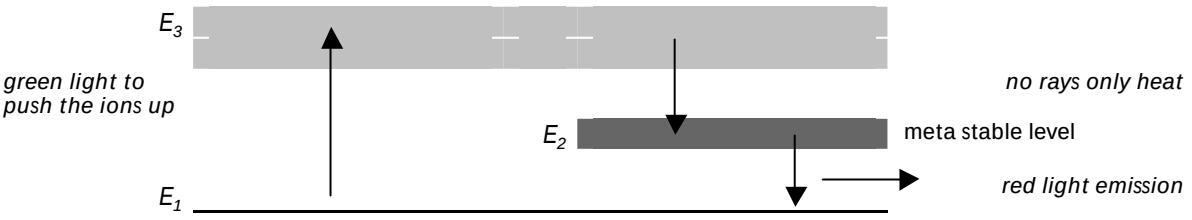
To create a narrow and intense beam of coherent light it is not enough to have a LASER active material and to create a stimulated emission. You can create more intensive light by putting your LASER active material between two mirrors.
With this trick the amplified light will be thrown back and forth by the mirrors and the number of coherent photons increases. This basic element of a LASER is called optical resonator.
To get the most out of the LASER the distance between the mirrors has to be a factor of the half wavelength of the emitted light. Only with this parameters you will get a stable wave in the optical resonator.
Looking at the dimension between the mirrors there is a space from 10cm to 1m; enough space for up to 1.000.000 light waves.
The main functionality of this element is not only to create a feedback on the amplified wave and the active material it has a influence on the type of emission too.
At the moment our light is captured between the mirrors. We will now make one of them semi-transparent. This leads to the fact that only those rays that are exactly parallel reflected by the mirrors can leave the resonator. All other rays have no effect on the amplification.

more power

The power of a LASER can be even more improved. We change to pulsed mode. This means that the semi-transparent mirror is replaced by a triggered one. Now we create common LASER light but we only open the emission mirror if we have collected enough photons. This creates a very short LASER impulse in which all of the collected energy is concentrated to a very short period of time. This procedure is called Q-Switch and you can reach energy of some Gigawatt but only for 10^{-11} to 10^{-8} seconds. In comparison a ruby LASER in normal mode reaches only 1 watt.

The ruby LASER

The first LASER made from a hard material was the ruby LASER; it was first build in 1960. It consists to 99.95% of AlO2 and the remaining 0.05% are Cr. Those less Cr-Ions are responsible for the LASER effect. Cr-Ions have three energetic levels E_1, E_2 and E_3. E_1 is the base energy level and E_3 is the level when we penetrate the ions with green light which has a short wavelength. To pump the ions we usually use a xenon lamp.
Now that we have some ions pushed to the highest energy level they will drop immediately back to E_2 but without emitting any light only heat. The Cr-Ions will stay a long time on this medium energy level therefore it is called meta stable.
If one ion drops back to E_1 spontaneously it will emit a photon with the energy $hf=E_2-E_1$ and forces the other Cr-Ions to initialise the LASER process.



There are of course many other possibilities to build up a LASER but the light emitted by a ruby LASER is red and in the visible part of the electro magnetic waves.
Due to this fact and because of the possibility to run a ruby LASER in almost every surrounding this type of LASER is very popular and it will be used for very many physical experiments.

Usage of LASERs

You can find LASERs in almost every household today. In Laser printer, CD-ROMS, audio CD players, DVD players and many more.
But there are some other things you can do with a LASER. Due to the very high bandwidth of a LASER beam it is obvious that is will be used to transmit data. Making a telephone call you will only use a bandwidth of 3KHz and 20KHz are enough to listen to a song with a radio in good quality. When you watch TV you will need at least 5MHz. By using radio antennas and open air data transmission the maximum bandwidth will be 12GHz.
Regarding a HeNe LASER with a frequency of nearly $5*10^{14}$ Hz it would be possible to transmit 1.000.000.000 telephone call or 1.000.000 television channels at once. By using typical protocols and if you want to guarantee a stable line it is possible to reach nearly $6*10^{10}$ Bits per second.

There is also some special usage of LASERs, like creating holographic images or to make high speed photo shots of very fast moving objects.