Adam's Laser Notes

Adam Orin

July, 2005

1 LASER Fundamentals

LASER stand for "Light Amplification by Stimulated Emission of Radiation." Light that is emitted by a laser is coherent, which just meansthat the emitted light rays are parallel, which means that the emitted waves are place waves. Laser light is also of one particular wavelength, or more correctly, a very narry range of wavelengths.

There are several ways to create laser light. They oare often designated by the medium that creates the light. From www.howstuffworks.com:

- Solid-state lasers have lasing material distributed in a solid matrix (such as the ruby or neodymium:yttrium-aluminum garnet "Yag" lasers). The neodymium-Yag laser emits infrared light at 1,064 nanometers (nm). A nanometer is 1x10-9 meters.
- Gas lasers (helium and helium-neon, HeNe, are the most common gas lasers) have a primary output of visible red light. CO2 lasers emit energy in the far-infrared, and are used for cutting hard materials.
- Excimer lasers (the name is derived from the terms excited and dimers) use reactive gases, such as chlorine and fluorine, mixed with inert gases such as argon, krypton or xenon. When electrically stimulated, a pseudo molecule (dimer) is produced. When lased, the dimer produces light in the ultraviolet range.
- Dye lasers use complex organic dyes, such as rhodamine 6G, in liquid solution or suspension as lasing media. They are tunable over a broad range of wavelengths.
- Semiconductor lasers, sometimes called diode lasers, are not solid-state lasers. These electronic devices are generally very small and use low power. They may be built into larger arrays, such as the writing source in some laser printers or CD players.

All of these lasers use the same underlying principles to function. We throw lots of energy into the system which creates a population inversion, and as the system relaxes, it emits light.

We'll go through the basics of a solid state Ruby laser to understand what's going on.

A simple ruby laser can be made out of a ruby rod, with one end mirrored, and the other half-mirrored. The rod is electrically neutral, no it must have some electrons inside to balance out the atoms. The atoms are arranged in a crystal lattice. So, we can approximate the electric potential that an electron would feel from the atoms as a square wave. Ignoring electron-electron interactions (why can we do this?), the Hamiltonian for one electron would be

$$\hat{H} = \frac{\hat{p}^2}{2m} + V_{square}(x, y, z)$$

It turns out the allowed energies for this kind of a system are (essentially) continuous ranges, with gaps. So the electron can have total energy in the range [1 eV, 2eV], or [3 eV, 4 eV] (note: I made these numbers up). But the electron cannot have energy in the range (2 eV, 3 eV). The allowed ranges of energies are called *bands.* The forbidden zones of energies are call *band gaps*, becuase they are gaps in the allowed bands of energy.

So, we have a bunch of electrons in the laser rod, which can have energies as described above. Normally, they all sit in the lower energy band. But we are going to pump energy into the rod, and excite all the electrons into the upper band. We do this with a flashlamp. A flashlamp is just a really lamp that makes a bright flash, like a camera flash. The flashlamp goes off and the light excites all the electrons into various energy levels in the upper band.

Our goal with the flashlamp is to create a *population inversion.* A population inversion occurs when there are more electrons in the excited state (the upper band) than in the equilibrium state (lower band). That's what the bright flashlamps do; they infuse enough energy into the system such that most of the electrons are excited into the upper band.

Now that the flashlamps have fired, and we have a population inversion, what comes next? The electrons have various energies allowed in the upper band, from 3 eV to 4 eV. They quickly fall down to the lowest energy of the upper band, 3 eV, by emmitting photons. Now they are all sitting with $E = E_3 = 3$ eV, and ready to fall across the band gap to $E = E_2 = 2$ eV.

Via spontaneous emission of radiation, one of the electrons falls back down to $E = E_2 = 2$ eV and emits a photon of energy $E_3 - E_2 = 1$ eV. This photon flies in some random direction in the laser rod. Now, in the presence of this photon, other electrons are more likely to fall down to E_2. This is called stimulated emission of radiation. In the presence of a photon of energy $E_3 - E_2$, the rate at which electrons fall to E_2 and emit photons is higher than the spontaneous emission rate. Also, 1 eV photons of emitted in the presence of the initial photon will have the same phase and movie in the same direction of the initial photon. We're getting coherent light out!

So, the initial 1 eV photon creates an 'avalanche' of photons moving in the same direction and with the phase. But, this avalanche is moving in some random direction. It will most likely leave the ruby rod and that will be the end of it.

But, one photon will be spontaneously emitted and move along the laser rod. It stiumlates emission more 1 eV photons of identical phase and direction. The avalanche grows. The photons reach the mirrored end of the laser rod and is reflected. The group travels through the laser rod again, and causes even more photons to be emmitted. When the photons reach the half-mirrored face of the rod, half of them leak out, and half are reflected to continue the process. The rod starts to emit laser light through the half-mirrored face. As the photons bounce back and forth through the rod, they stimulate more emission, and the laser pulse gains intensity. Eventually the population inversion is lost. Most of the electrons are back in the lower band, with energy [1 eV, 2 eV]. The pulse becomes dimmer and eventually dies out.

??Why doesn't the laser output look like a bunch of pulses, one for each time the group of photons reach the half-mirrored surface??

To get another laser pulse out, we just have to fire the flashlamps again!

2 APOLLO Laser Overview

3 APOLLO Laser Vocabulary

- Amplifier: This is a second laser rod. When the laser pulse is powerful enough, it is sent through the amplifier rod. The amplifier has it's own flashlamp (powered by the Marks bank) to create a population inversion.
- Acousto-optic mode locker: This sits near the top o fthe cavity. It becomes transparent/opaque at a frequency of about 70 MHz. When the laser pulse is about to fly through it, it is transparent, and it is opaque otherwise. Thus, it's job is to create a small laser pulse about ?? ns in size. Note that this is still much larger than the final 200 ps pulse.
- Capacitor Banks: These sit in the top of the cabinet and provide the juice to fire the flashlamps.
- Cavity
- Cooling Group: The cooling group sits in the bottom of the laser rack in the ILE. It cools the laser. It pumps de-ionized water from the ILE to the laser. The large chiller connects to it, and cools the returning water. But the chiller's fluid and the cooling groups fluid remain seperate. When the cooling group does not need the chiller's fluid to cool, it stops the chiller's flow. You will notice the chiller beep and give a low flow warning when this happens.
- CU-601: This is the main laser control unit. It sits in the laser rack in the ILE.
- Dichroic: A dichroic is an optic that reflective for a range of wavelengths, $(\lambda_1, lambda_2)$, and absorbant to the rest. We have three dichoics. The main one sits at the main exit of our laser. Green light is reflected out of the laser box, while the junk transmits through to a beam dump. Another dichoic sits behind this dichroic, and reflects what greet light is left out to our fast trigger photodiode. The third dichroic sits in front of the main dichroic, and can be flipped into and out of the beam. When it is in the beam, it reflects the green light to a power meter, so that we can measure the power output of the laser.

- Flashlamps: These are bright lights that excite electrons in the laser rod, creating the population inversion.
- Keyswitch: The CU-601 has a key that is the main enabler for the laser. Power is handled by a breaker on the bottom of the rack.
- Marks Bank: This connects to a photodiode and has a bunch of capacitors inside it. When the laser pulse in the cavity is bright enough, it fires and power's the amplifier's flashlamp.
- MV-70: This is the frequency generator for the AOML. It's set around 70 MHz, since the round trip time for the laser pulse in the cavity is 10^{-8} s.
- Oscillator
- POCL Cell
- PU610: This poewrs the oscillator.
- PU620C: This is the control unit for the amplifer.

4 APOLLO Laser Operating Instruction