

Building a Nitrogen Laser

Theory

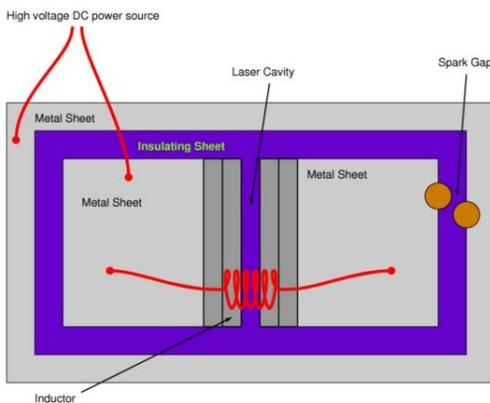
How a Laser Works:

When atoms get excited (gain energy) their electrons move up energy levels. A population inversion occurs when over half of a population of atoms is in the same excited state (probably metastable). When these electrons decay back down to their ground state a photon is emitted that has an energy ($E=h*f$) equal to the difference between the energy levels of the drop. If a photon passes an atom in an excited state, and this photon has an energy equal to an energy drop that an electron in the excited atom can make, then the photon stimulates the electron to drop to the lower energy level. When this happens, a photon with the same frequency and phase with the photon that passed the atom, is emitted. This process is called stimulated emission. When stimulated emission occurs in the presence of a population inversion, the photons emitted will all be of the same frequency and in phase. This emitted light is laser light, where LASER is an acronym for Light Amplification by Stimulated Emission of Radiation).

How a Nitrogen Laser Works:

A nitrogen laser uses electricity to excite the nitrogen. When an electric spark crosses the spark gap in the laser, the electrons will hit the nitrogen atoms in air, exciting them into a metastable state. When a photon with a wavelength of 337.1nm passes excited nitrogen atoms, stimulated emission occurs and a laser will be formed.

Design



As you slowly charge the top metal sheet, the inductor will allow charge to flow into the other top sheet. This will make the two top sheets charged oppositely from the bottom metal sheet. When the electric field ($E=V/d$) reaches the breakdown point of air, a spark will occur over the spark gap charging the top metal sheet attached to the spark gap the

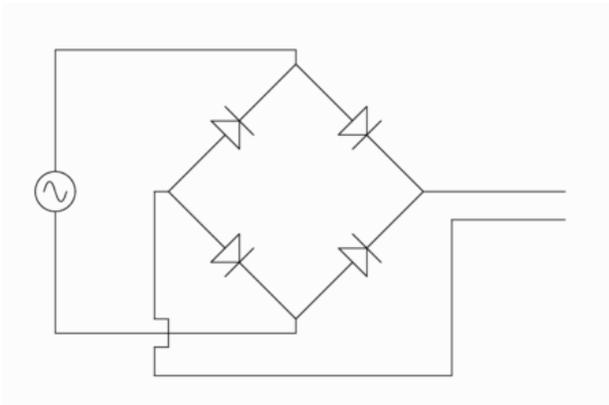
same as the bottom metal sheet. The inductor will no longer let the charge flow through it, because it strongly resists rapid changes in current ($V = -L \frac{dI}{dt}$), so the two top metal sheets will be oppositely charged and the large electric field within the laser cavity will generate a large spark as the electrons arc across it to neutralize the two top plates.

Why there are No Mirrors:

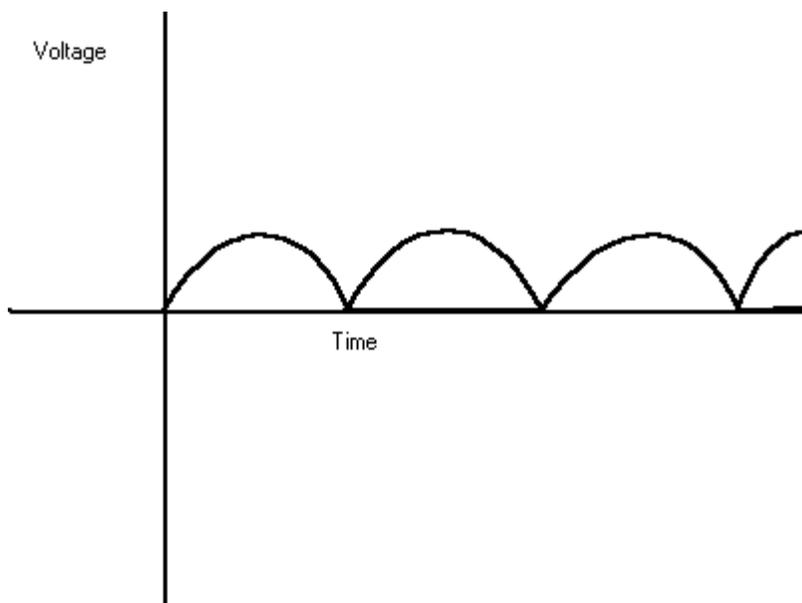
The purpose of laser mirrors is to send photons back through the laser cavity many times to further amplify the light emitted. The reason that this is unnecessary in a nitrogen laser is that, by the time that a photon emitted from one end of the laser cavity reaches the other end, the laser is near the limits of its amplification, so the laser light is already sufficiently amplified. However, if a mirror were to be placed on one end of the cavity the power output on the other end will be more than doubled (Stong, pg 8), but if two mirrors are used (as is needed for most lasers) the laser will no longer work because the nitrogen will no longer lase efficiently and all the energy of the laser beam will be converted into heat.

Power Source:

There are three things that are important about the power source used; that it is DC, that it is high voltage, and that the voltage can be turned up slowly to adjust the rate of charge accumulation and rate of sparking. We used a variac (a variable transformer that allows you to vary the voltage that you get out of a wall socket) to adjust the voltage. We hooked the variac up to a transformer that increased the peak voltage by 93 ± 2 times. The high voltage AC power was rectified to DC using the following diode circuit:



This gave us a power source that looked similar to this:



It is not necessary, and is probably detrimental, to level off the output of this source, because that would lower the peak voltage to the rms value, so you would not be getting as much voltage out of the system.

Original Model:

In the first model we mounted everything onto a wooden board and then covered the top of with aluminum foil. We used overhead transparency sheets, one layer thick, as the insulator, aluminum foil for the top metal plates, aluminum U's for the laser cavity, and copper pennies (made prior to 1983) for the spark gap. We replaced the top metal plates for solid aluminum plates as we were worried that we might be getting too much coronal discharge from all of the tears in the aluminum foil, but we found it difficult to attach the wires to these plates because the tape was not working well and it is not easy to solder to the aluminum. We also tried changing the base to an aluminum box, but we found that this was giving us too much coronal discharge. We also tried building a new spark gap out of some plastic tubing, a metal top, and a screw through the top, thinking that this would give us more precision in changing the gap, but found that the inductance from this gap configuration reduced the spark speed by too much. We exchanged the aluminum U's for hacksaw blades because they would be less sensitive to alignment and instead of needing one uniform spark across the cavity a lot of separate sparks would work, but we had no luck with this.

When we felt that our alignment was pretty good, we tried taking advantage of the photoelectric effect by shining UV light on the laser cavity, hoping to increase the number of electrons jumping across the cavity, but we had no success with either a corona wire or a powerful UV light source.

Final Design:

We ended up using the wooden base covered with aluminum foil that we started with. We continually had problems with holes being burnt through the overhead sheet, to the point where the amount of carbon was enough to conduct through the patchwork, so we replaced the old sheets with new overhead sheets but this time we made them three layers thick and put Teflon underneath the spark gap. We changed the top metal plates to copper sheets because it is possible to solder to copper; we reverted back to the pennies for the spark gap, and we used smooth, straight aluminum L's for the laser cavity with nylon screws threaded through them for precision alignment.

We also built a vacuum chamber to enclose the laser cavity with two openings, one for a vacuum pump and the other for nitrogen gas. We did this because it is better to have flowing nitrogen than stagnant nitrogen and the reduced pressure allows the nitrogen to stay excited longer because the nitrogen atoms will have fewer collisions at low pressure and will therefore not transfer energy as rapidly.



Numbers

- Capacitance- we found the capacitance of our system to be $3.2 \pm 1 \text{ nF}$
- Voltage- We got the laser to run off $7719 \pm 234 \text{ V}$ to our maximum voltage (the highest voltage that we could produce) of $10881 \pm 234 \text{ V}$

- Electrical Field Breakdown of Air- 3000V/mm (Kraus)
- Spark Gap- our gap ranged from 2.6 ± 0.1 mm- 3.6 ± 0.1 mm
- Laser Cavity-our laser cavity was fixed at 1.18 ± 0.1 mm (this large uncertainty cannot be helped because this measurement had to be taken from outside of the vacuum, so because of its small size and the inability to get close, this uncertainty must remain large)
- Electric Field of Laser Cavity-We found a range of electrical fields that got the nitrogen to lase between 6541.5 ± 589 V/mm- 9221.2 ± 806 V/mm

How We Could Tell that it was lasing

We had two fluorescent objects: Fluorescein dye and TLC (thin layer chromatography) plates. The light that we saw emitted by the fluorescent objects was round and bright at one point. If the nitrogen laser was not lasing than the light would be more spread out, and would not be in a circular shape, but in the shape of the cavity. We could also run the light through a diffraction grating and observe a diffraction pattern, shown below.



Conclusions

Once you obtain a voltage that is sufficient to get the nitrogen to reach its metastable state the alignment is crucial for lasing. A vacuum can increase the power of the laser, but we found that once we got it to lase, it lased with or without reduced pressure or flowing nitrogen. We did find that reducing the pressure to about .5atm of only nitrogen did increase the power, but the power decreased noticeably when the pressure dropped below about .3atm.

The light is not collimated so it will not travel very far as a beam unless lenses are used to collimate the light, so it is difficult to see any sort of light more than 30cm away from the laser cavity. We were, however, able to diffract the

light by using a diffraction grating with 500 lines per millimeter (see above picture).

References

We began our work with the article [An unusual kind of gas laser that puts out pulses in the ultraviolet](#) from “The Amateur Scientist” column of the June 1974 issue of *Scientific American*.

Professor Mark Csele of Niagara College has a good web site to learn both the theory and experimental details of building nitrogen lasers.

<http://www.technology.niagarac.on.ca/people/mcsele/lasers/LasersN2.htm>

<http://www.technology.niagarac.on.ca/people/mcsele/lasers/LasersTEA.htm>

A critique of the *Scientific American* article discussing the physics behind the laser.

<http://www.jonsinger.org/jossresearch/lasers/nitrogen/rant.jimsmall.html>

Sam Goldwasser's Laser FAQ contains much information and many nitrogen laser resources.

<http://repairfaq.ece.drexel.edu/sam/lasercn2.htm>

Hubert's laser page describes an Air laser that can be built for \$10.

<http://spt06.chez.tiscali.fr/00/air.htm>

Hubert's site also has several nitrogen laser links

<http://spt06.chez.tiscali.fr/00/air.htm>