DIY Nitrogen TEA Laser

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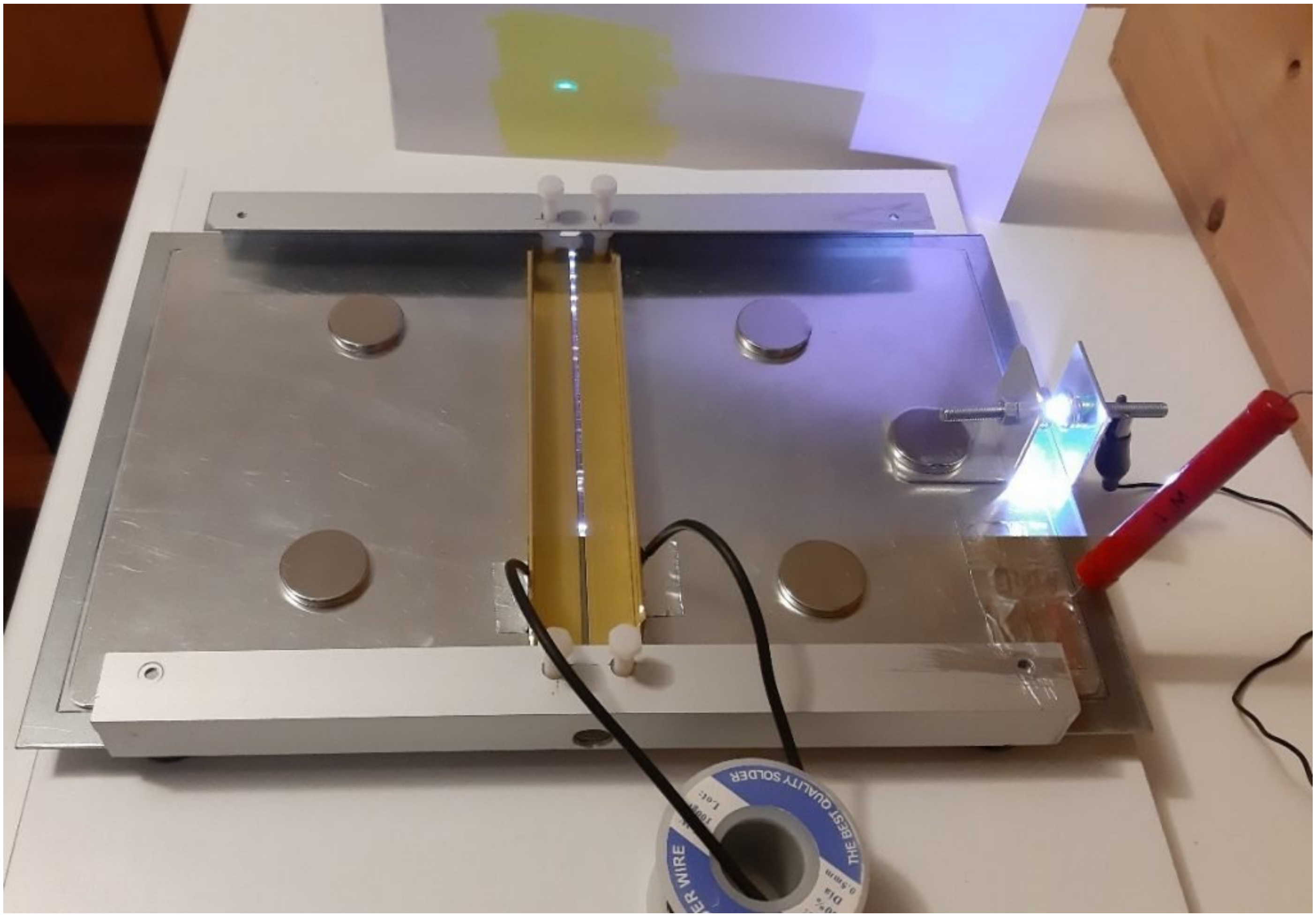
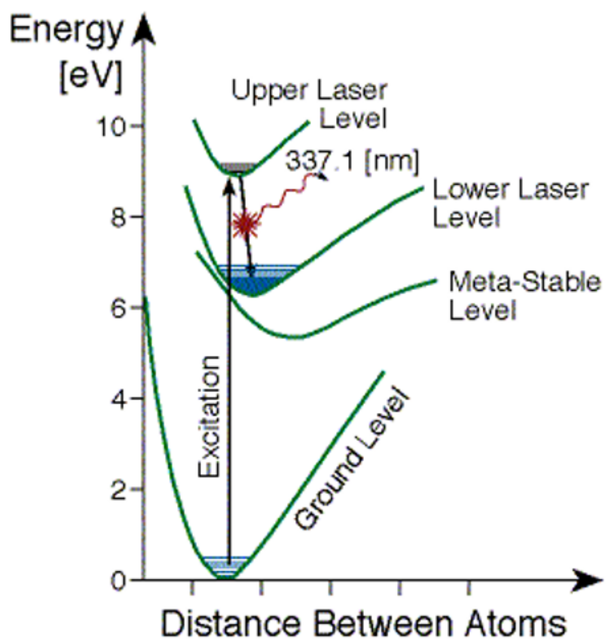


Abstract : *in the cover image the homebuilt TEA nitrogen laser in use at PhyscsOpenLab. The entire laser is 'open air' and is built into an aluminum / iron chassis with brass electrodes. The triggering spark gap is visible in the right side while the transverse discharge along the electrodes gives rise to a UV laser pulse visible as the green fluorescent spot on the paper. This class of lasers produces pulses of light using a Transverse Elecrical discharge in gas at Atmospheric pressures. Since atmospheric pressures are used, no vacuum system is required making this an inexpensive laser to construct. TEA configurations are used for*

some nitrogen as well as carbon-dioxide lasers. For a nitrogen TEA laser, it is possible to use 'open air' as the lasing gas since air is 78% nitrogen !

Introduction



Nitrogen Laser is an example of ***vibronic*** laser. This laser has its most important oscillation at **λ = 337 nm (UV)** and belongs to the category of **self-terminating** lasers. The energy level scheme for the N2 molecule is shown in the figure aside. Laser action takes place between the Upper level and the Lower level (see the figure).

The radiative lifetime of the upper level is **40ns**, while the lifetime of the lower level is **10μs**. Clearly the laser cannot operate cw but it can, however, be excited on a pulsed basis provided the electrical pulse is appreciably shorter than 40ns.

Because of the high values of electric field required a TE (transverse) laser configuration is normally used. To obtain the required **fast discharge pulse** (5-10ns) the discharge circuit must have as low an inductance as possible. To achieve this the discharge capacitor is actually part of the discharge electrodes.

Owing to the high gain of the self-terminating transition, lasing takes place in the form of amplified spontaneous emission and the laser can operate even without mirrors. Usually, however, a single mirror is placed at one end of the laser since this reduce the threshold electrical energy and also provide a unidirectional output with lower beam divergence. The pulses that can be obtained are ~10ns wide with high peak power and a repetition rate up to 100Hz.

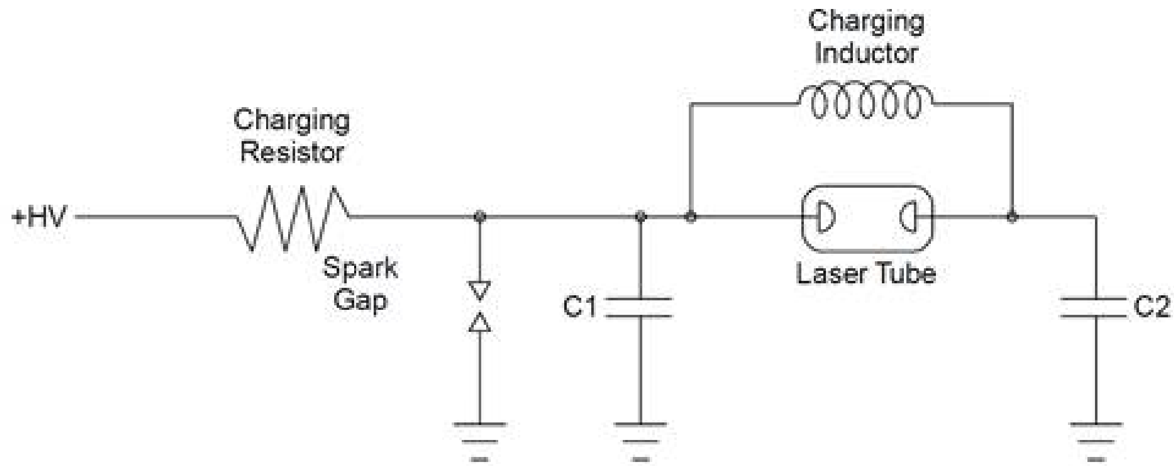
If the laser is operated at atmospheric pressure (760torr) the lifetime of the upper level is even shorter :

t = 36/(1+p/58) *where t is ULL lifetime in ns and p is pressure in torr*

at 760torr the pulse duration is about **2ns**, thus the electrical pulse must be really short !

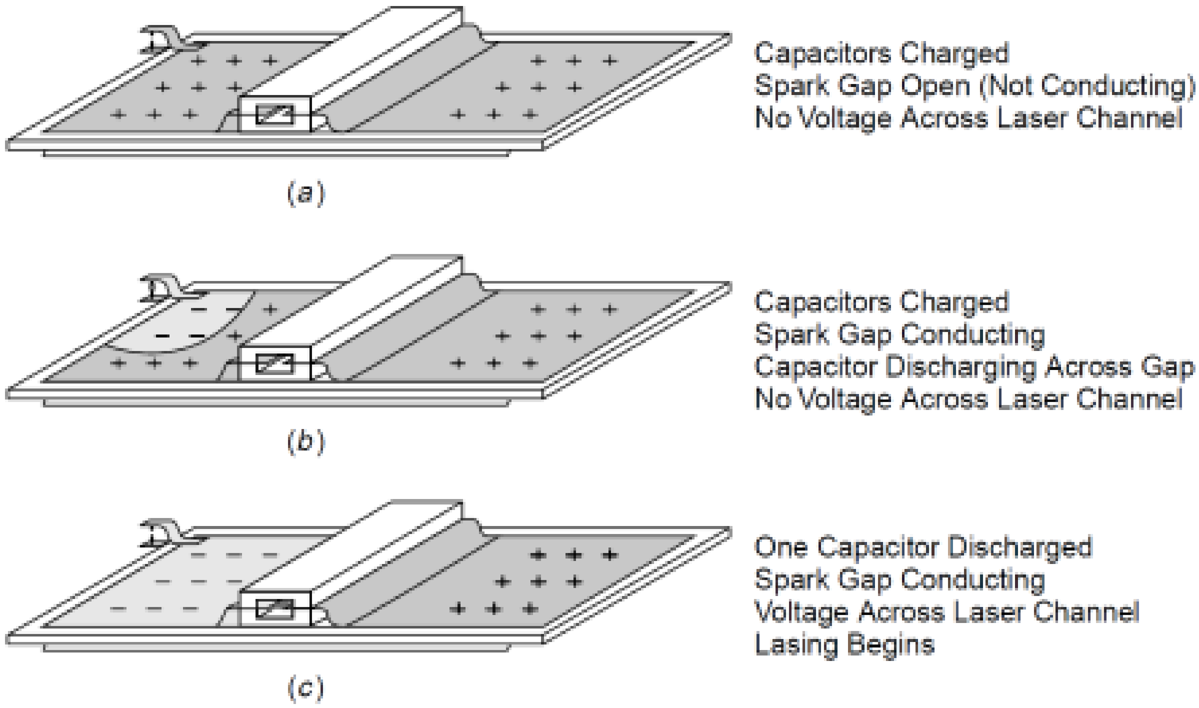
To obtain the fast discharge in the nitrogen laser we used a **pulse-forming network** (**PFN**). It is an electric circuit that accumulates electrical energy over a comparatively long time, and then releases the stored energy in the form of a relatively square pulse of comparatively brief duration for various pulsed power applications. In a PFN, energy storage components such as **capacitors**, inductors or transmission lines are charged by means of a **high-voltage power source**, then rapidly discharged into a load through a high-voltage switch, such as a **spark gap** or hydrogen thyratron. PFNs are used to produce precise nanosecond-length pulses of electricity to power devices such as klystron or magnetron tubes, pulsed lasers, particle accelerators, flashtubes, and high-voltage utility test equipment.

The circuit is shown in the scheme below. The **capacitor C1** is charged through the charging resistor while **C2** through the **charging inductor**; the maximum voltage that can be reached is set by the distance that separates the electrodes in the **spark gap**. When in the spark gap begin a discharge the capacitor C1 lose its charge and goes to the ground potential, the inductor prevents any current from flowing toward C1 so now there is a high voltage between the laser electrodes and the plasma discharge can take place in the laser channel.



Our circuit is a sort of **Blumlein line**. In the Blumlein generator, the load (the laser channel between electrodes) is connected in series between two equal-length transmission lines, which are charged by a DC power supply at one end. To trigger the pulse, a **switch short-circuits the line** at the power-supply end, causing a negative voltage step to travel toward the load. The voltage step is half-reflected and half-transmitted, resulting in two symmetrical opposite-polarity voltage steps, which propagate away from the load, creating between them a voltage drop of $V/2 - (-V/2) = V$ across the load. The voltage steps reflect from the ends and return, ending the pulse.

The diagram below shows the phases that take place during the discharge process.



The impedance of the Blumlein line can be calculated with the following equation

:

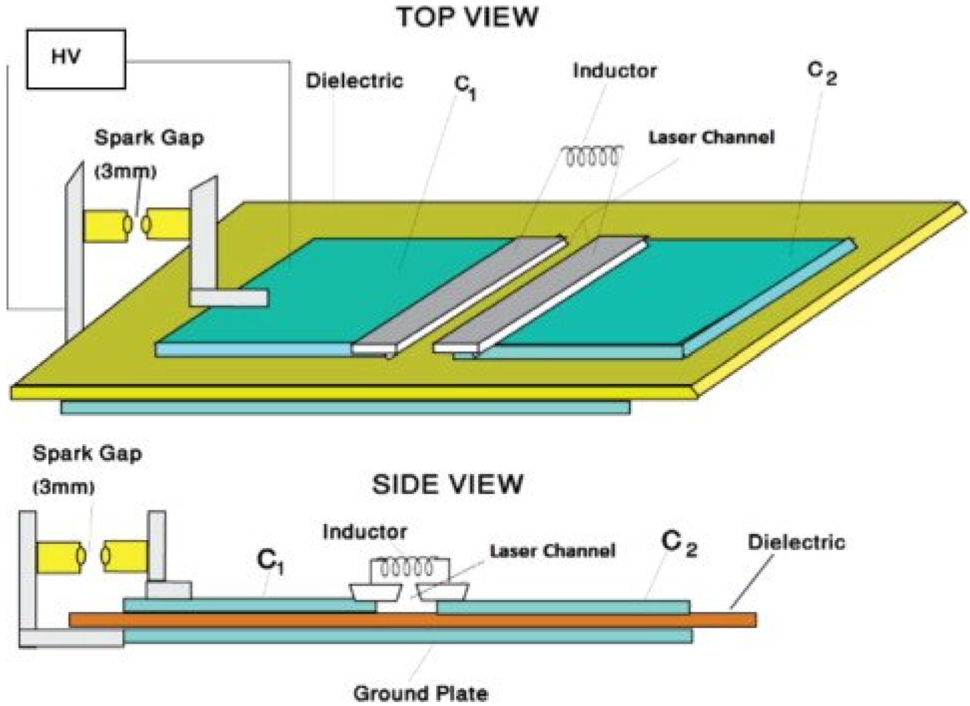
Z = 337/√εr * (d/d+w) *where εr is the dielectric constant, d the dielectric thickness and w the line width*

In our case εr=2.26, d=0.1mm, w=180mm -> **Z=0.12Ω**

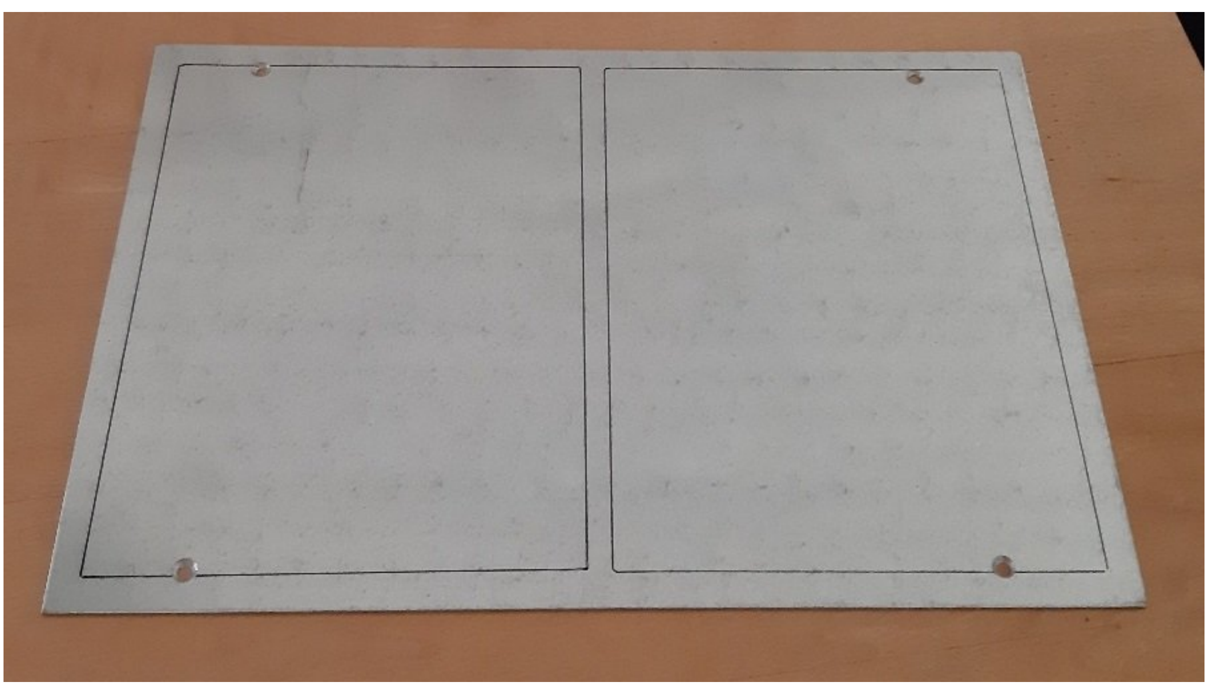
It is important, in order to achieve high discharge speed, to keep the impedance as low as possible.

Building the Laser

The construction scheme of the laser is shown in the following image.

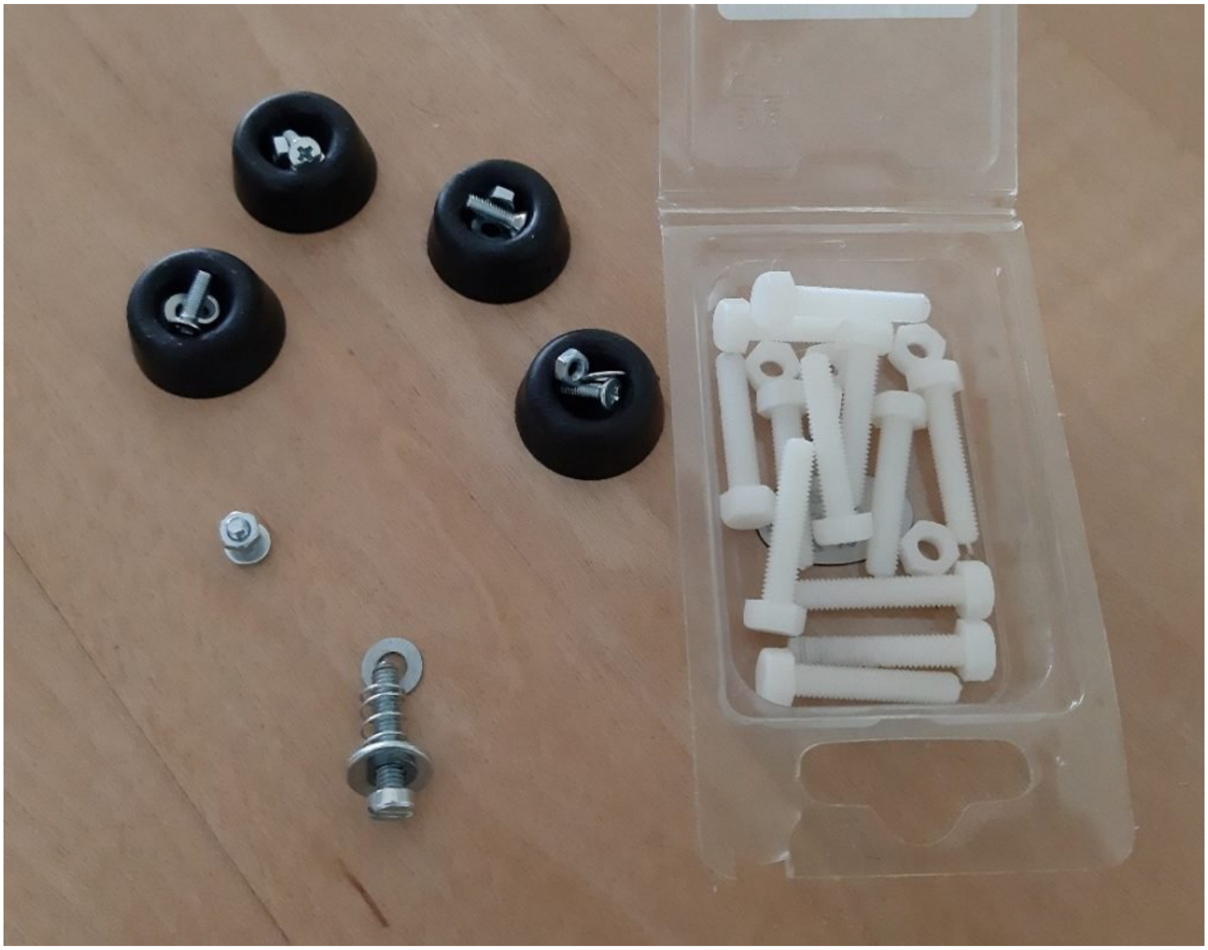


Our nitrogen laser is made on a **2mm** thick iron plate, with "A4" size **200x300mm**. The adoption of iron allows us to use permanent magnets for the positioning of the other elements. Two holes are drilled on the plate on each side on the two long sides for positioning the U-guides and the rubber supports. The holes should be countersunk so that the screws do not protrude. The image below shows the plate with the contours of the two electrodes marked with permanent marker.

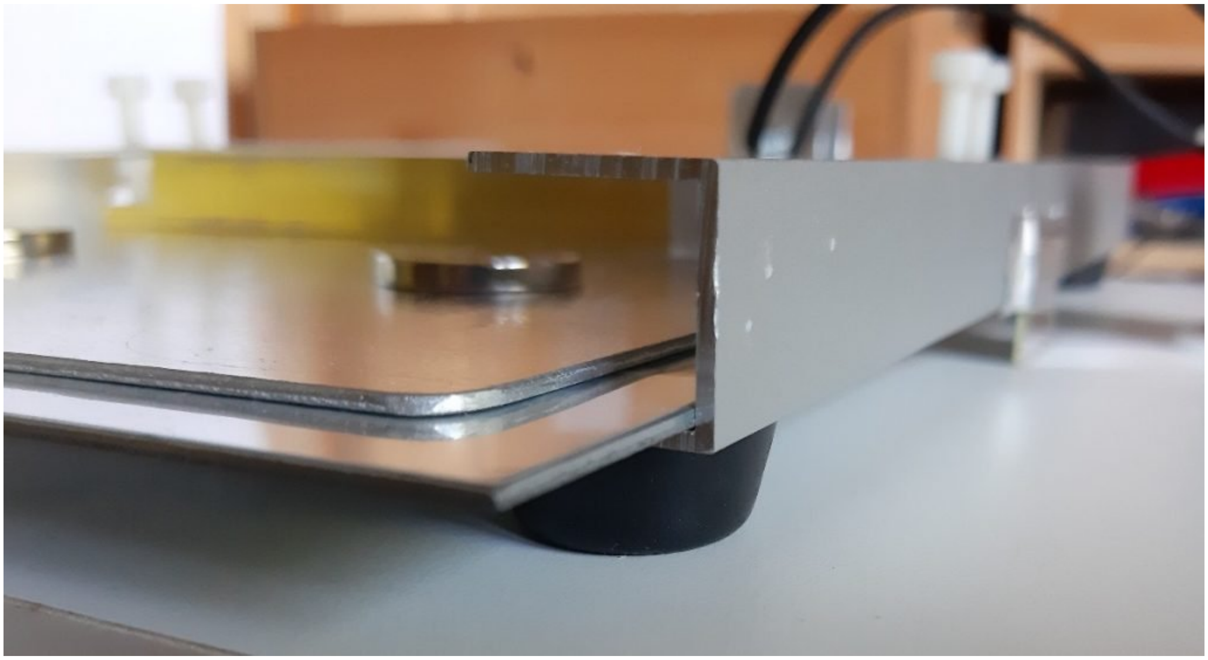


The base plate is mounted on two aluminum U-shaped guides with dimensions **20x20mm** and **1.5mm** thickness. The guides must be cut to a length shorter than the base, for example **250mm**, on the guides the holes must be drilled in correspondence with the holes made on the base. In addition, the holes for the plastic screws that hold the electrodes in place will be drilled, the threaded nuts for the plastic screws will be glued on these holes (with cyanoacrylate or loctite glue), as shown in the image below. The guides also have to be drilled in order to let out the laser beam.

The rubber feet and the plastic screws are shown below. The plastic screws could be **M4** or **M5 25-30mm** long.

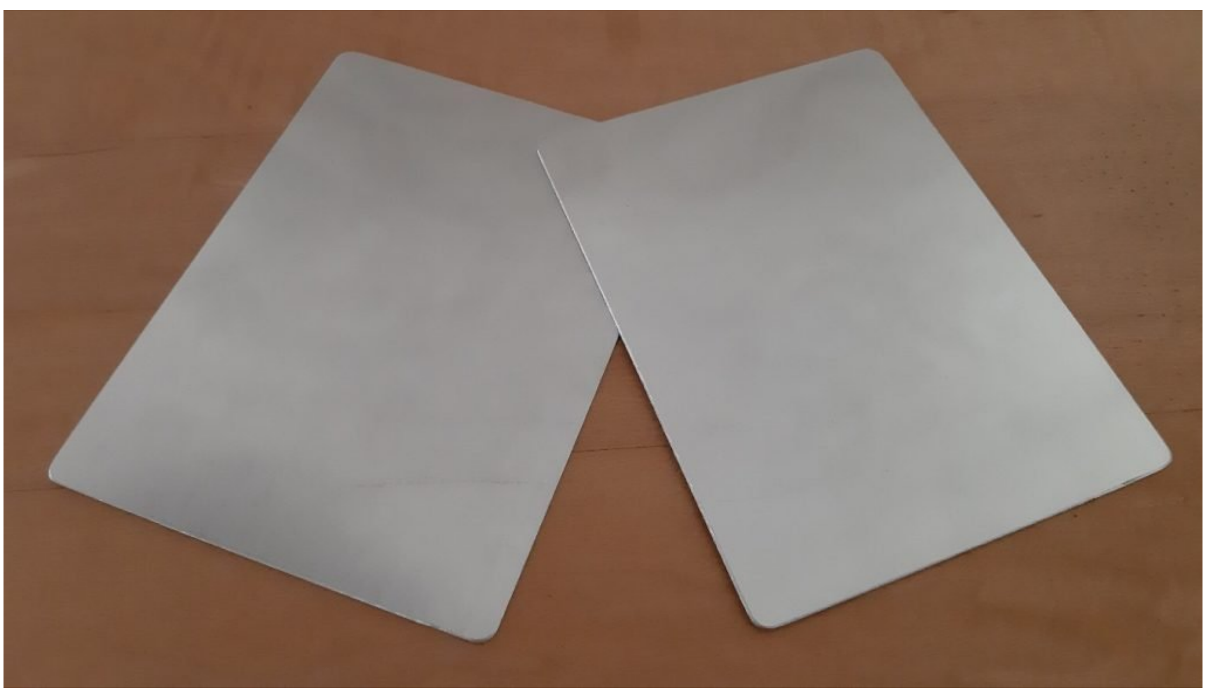


The image below shows the assembly detail of the U-rails, the base and the rubbers. Everything should be robust and well fixed, easily transportable and isolated from the table surface.



As dielectric we used a **0.10mm** thick A4 sheet of plastic, the type normally used as slides for projectors. It is important that the thickness is not greater than 0.10-0.15 mm, otherwise the charge that is accumulated in the two capacitors may not be sufficient to trigger the process of generating the laser beam. Thinner thickness can however be easily perforated by an electric discharge, therefore a compromise must be found that allows the correct operation of the equipment, 0.1mm should be fine.

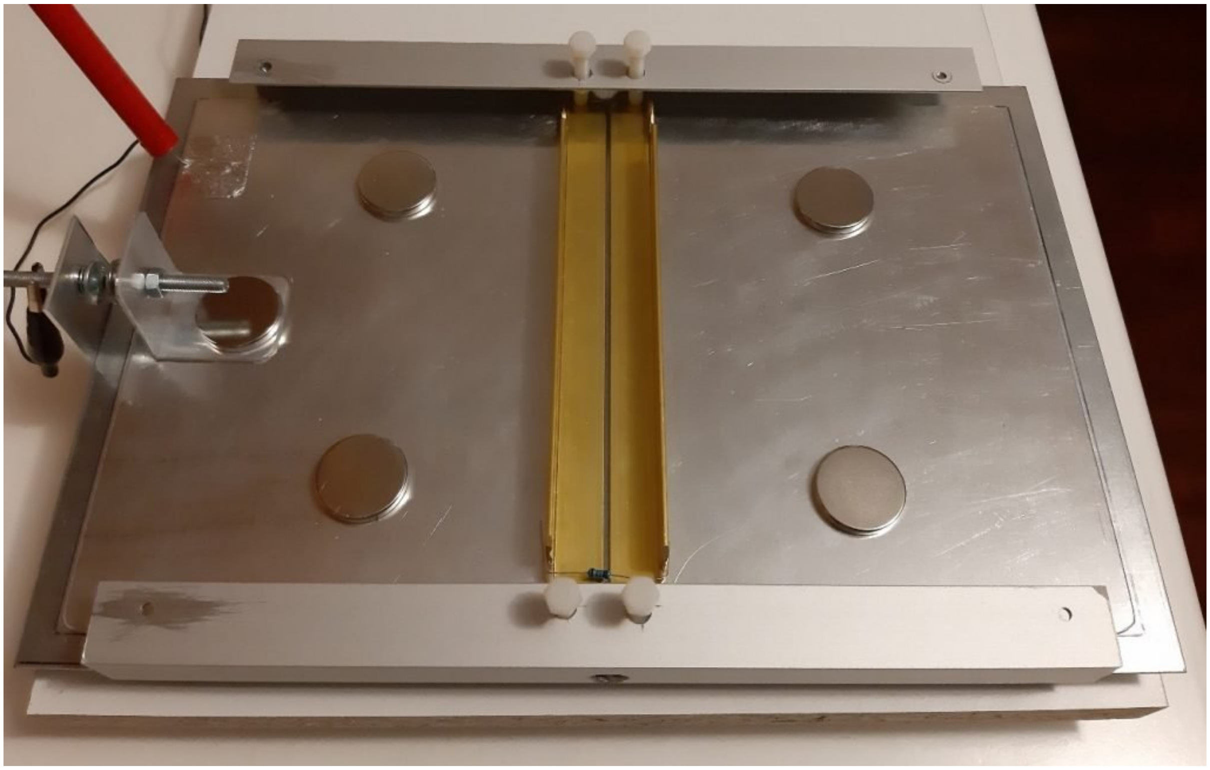
The two plates which make up the capacitors and which will be in contact with the electrodes are positioned above the dielectric. These are two aluminum plates, **1-2mm** thick and **135x180mm** in size. The figure below shows the two plates, with rounded edges to decrease the possibility of discharge. The two plates are held in place by **permanent neodymium magnets**, as shown in the following images.

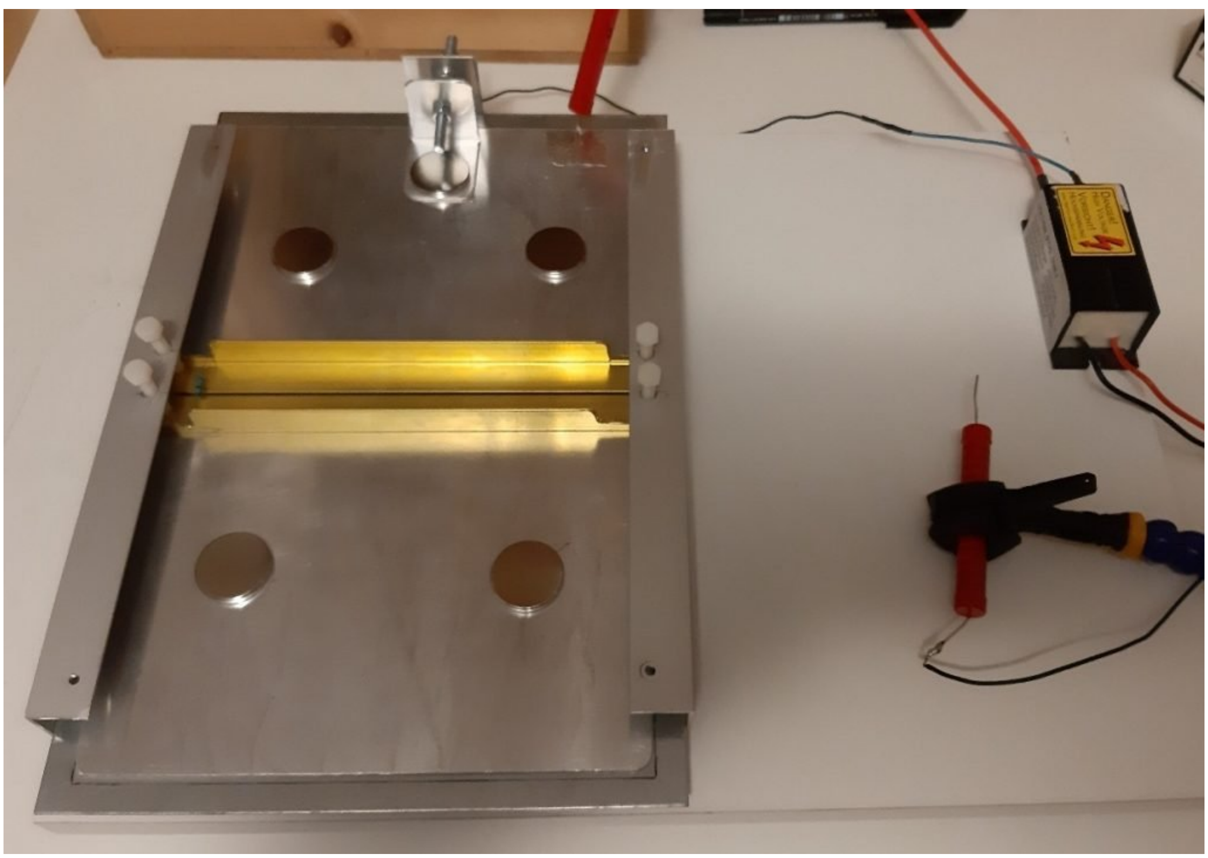


The basic component of the nitrogen laser are the electrodes. In the space between the electrodes placed side by side, which must be absolutely parallel and equally spaced, during the discharge a "strip" of **ionized molecular**

nitrogen is formed which constitutes the active medium of the laser. For this reason, the active surfaces of the electrodes must be absolutely smooth and parallel to each other, spaced **2-3mm** apart. For the electrodes we have chosen an L-shaped brass profile **1.5mm** thick and **15mm** side. We chose brass because it is less deformable than aluminum. The electrodes, **180mm** long like the plates, must be shaped so that they can be inserted below the U-profile, the edges must then be chamfered. The image below shows the two electrodes side by side.

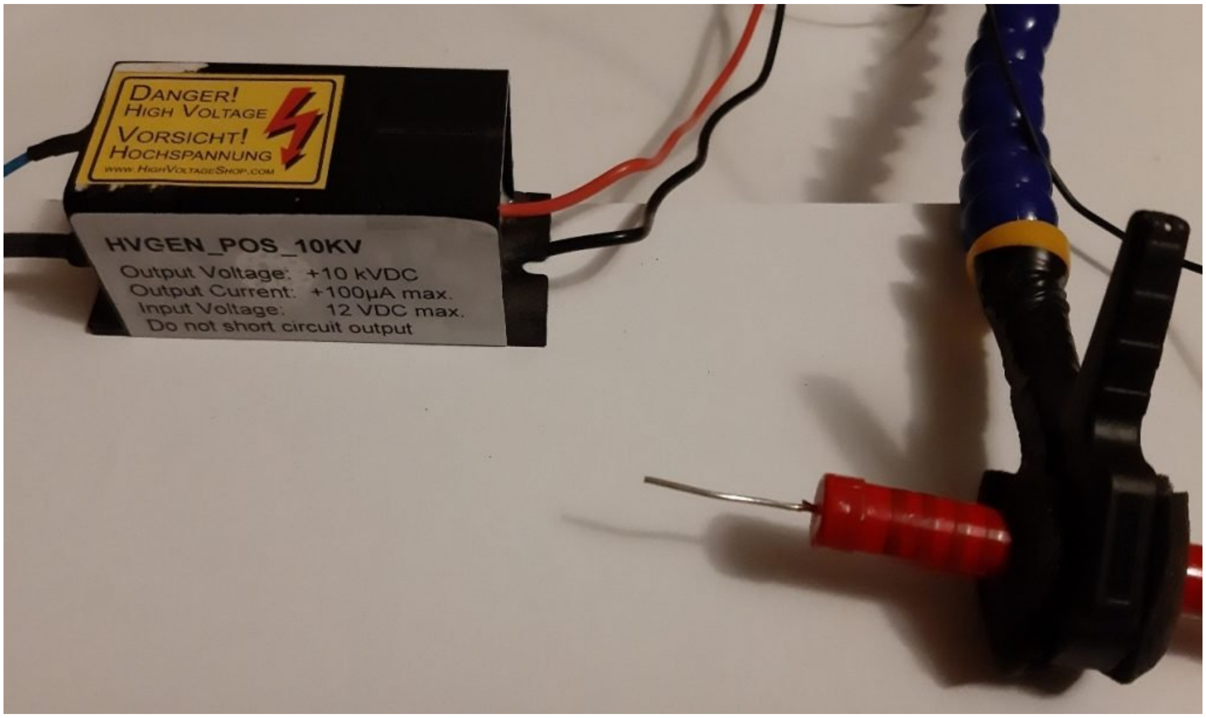
The following two pictures show the complete equipment. In the center are the two electrodes placed side by side and held in place by means of the plastic screws. The two electrodes can be put in contact with each other with a **resistor** or with an **inductor**, in the images below a resistor (**500KΩ**) was used straddling the two brass electrodes. The capacitor plates are fixed with disk magnets. On the left you can see the spark gap, which is also fixed with a disk magnet and at the top you can see the **1MΩ** HV resistor for connection with the **10KV** HV generator.



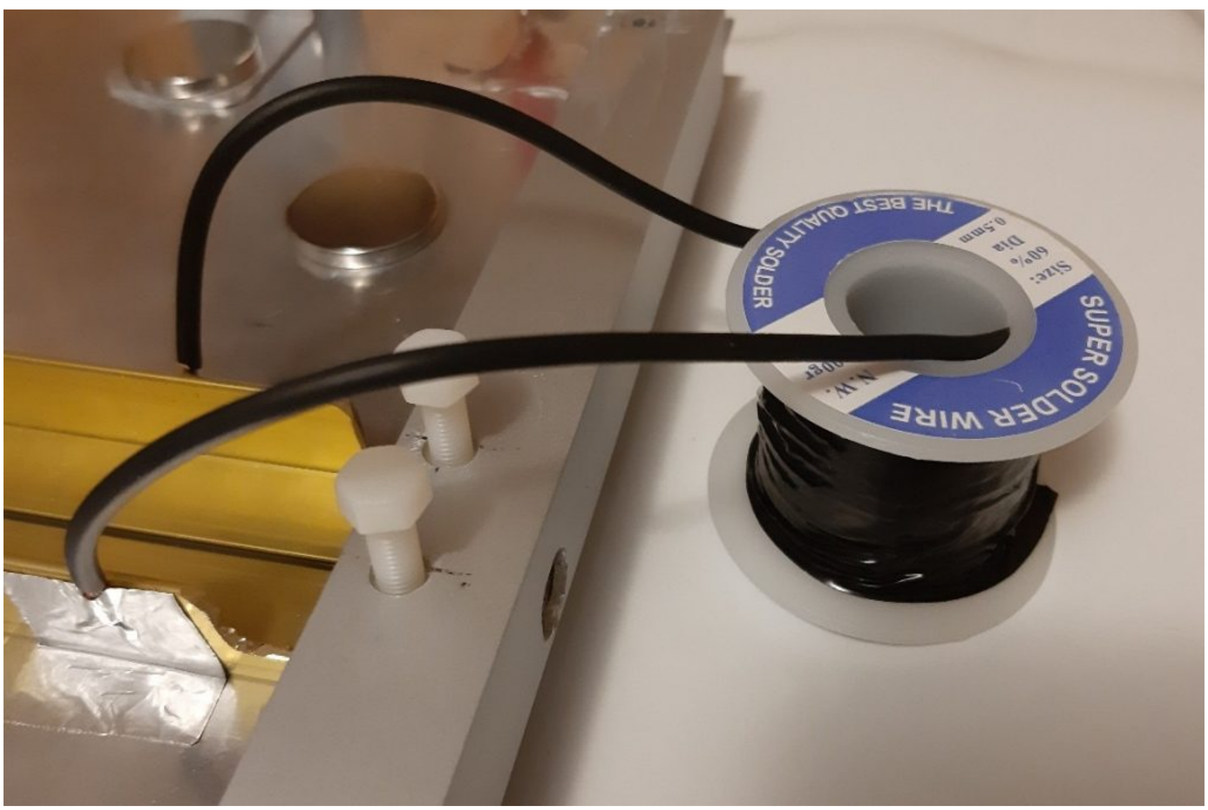


The image below shows the detail of the spark gap. They are two round head bolts held in place by two nuts and two compression springs. The two L-shaped brackets are fixed by disc magnets. The working distance of the spark gap is about **3-4mm**, the greater the distance and the greater the voltage and the energy of the discharge, however the risk of perforating the dielectric increases.

For the high voltage source we used a compact **10KV** generator powered by a **12V** battery. It is preferable to use battery powered small power generators capable of delivering only small currents, in this way there is less risk in case of accidental contact. To increase safety, it is good practice to connect the base plate to earth and prepare a “discharger” in order to discharge the capacitor plates after use. The image below shows the HV generator and our discharger consisting of a 1MΩ HV resistor connected to the negative / GND pole.



Instead of the resistor, an inductor can be used for the contact between the two electrodes, simply obtained by winding about twenty turns of an insulated electric cable around a plastic support, as shown in the image below.



Technical data & Materials

Ground plate : iron sheet 200x300mm, thickness 2mm

U-shaped guides : aluminum, 20x20mm, thickness 1,5mm, length 250mm

Rubber Supports

Nylon Screws and Nuts : M5x25mm or M5x30mm

Dielectric : plastic sheet, thickness 0,1mm

Capacitor plates : aluminum 135x180mm, thickness 1-2mm

Permanent Neodymium Magnets : diameter 25mm, thickness 3,5mm

Electrodes : brass, 15x15mm, thickness 1,5mm, length 180mm

Bias Resistor : HV, 1MΩ

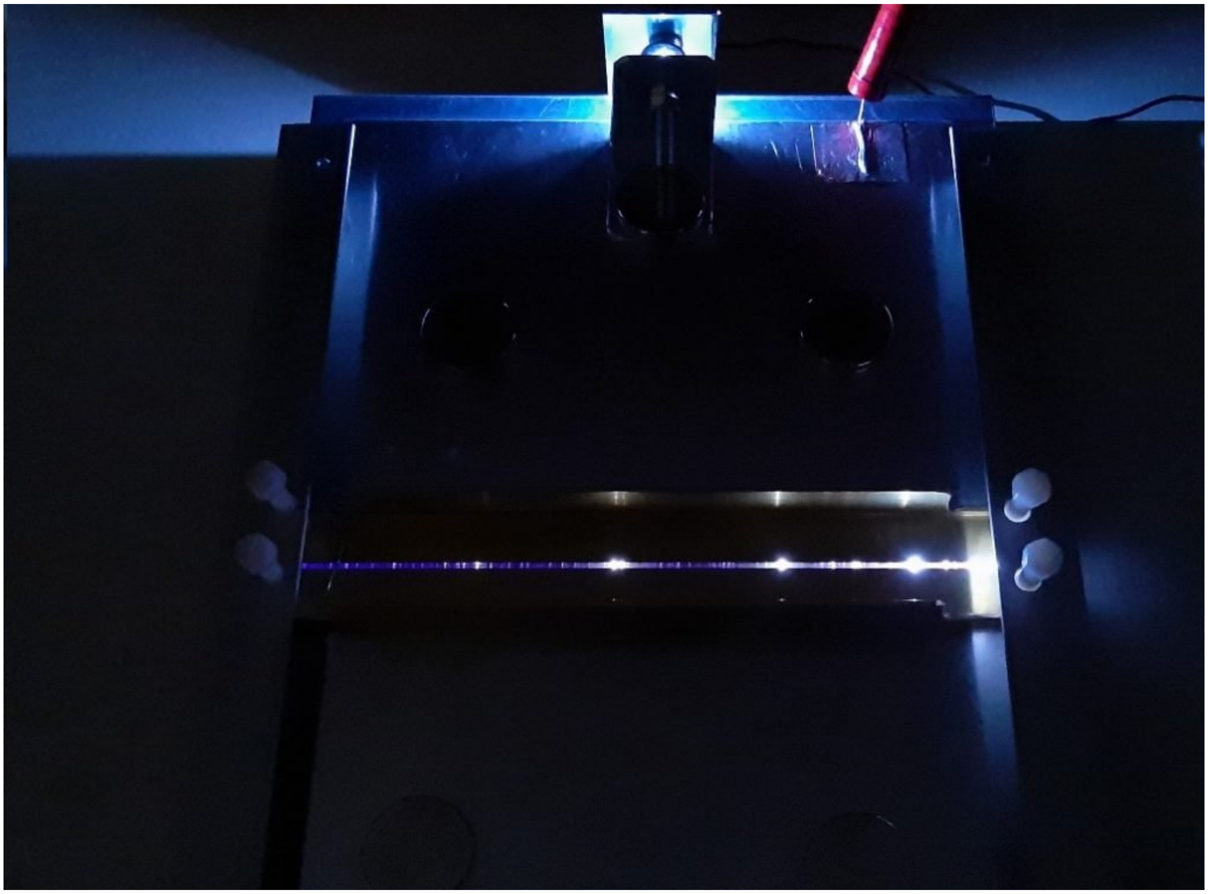
HV Generator : 12Vin – 10KV out

C1 measured : 3500pF

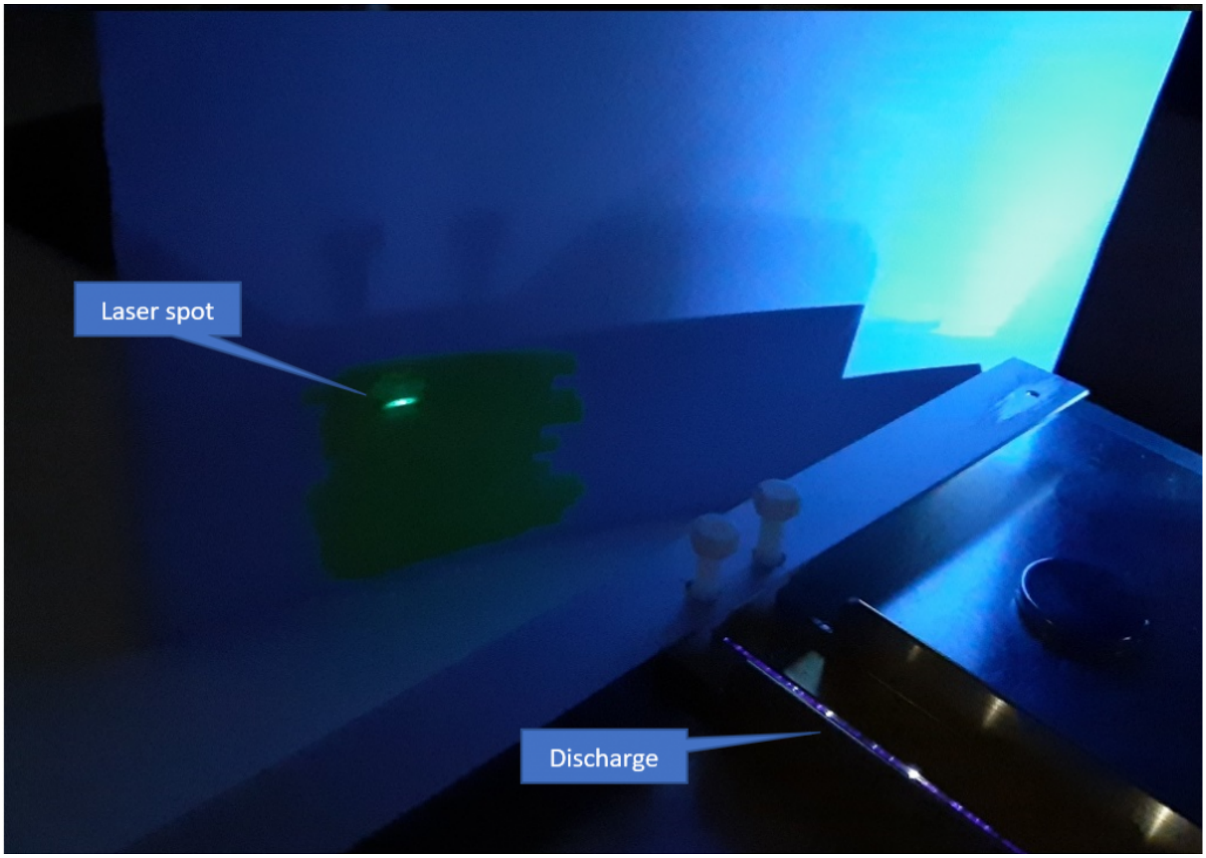
C2 measured : 4000pF

Laser in Action

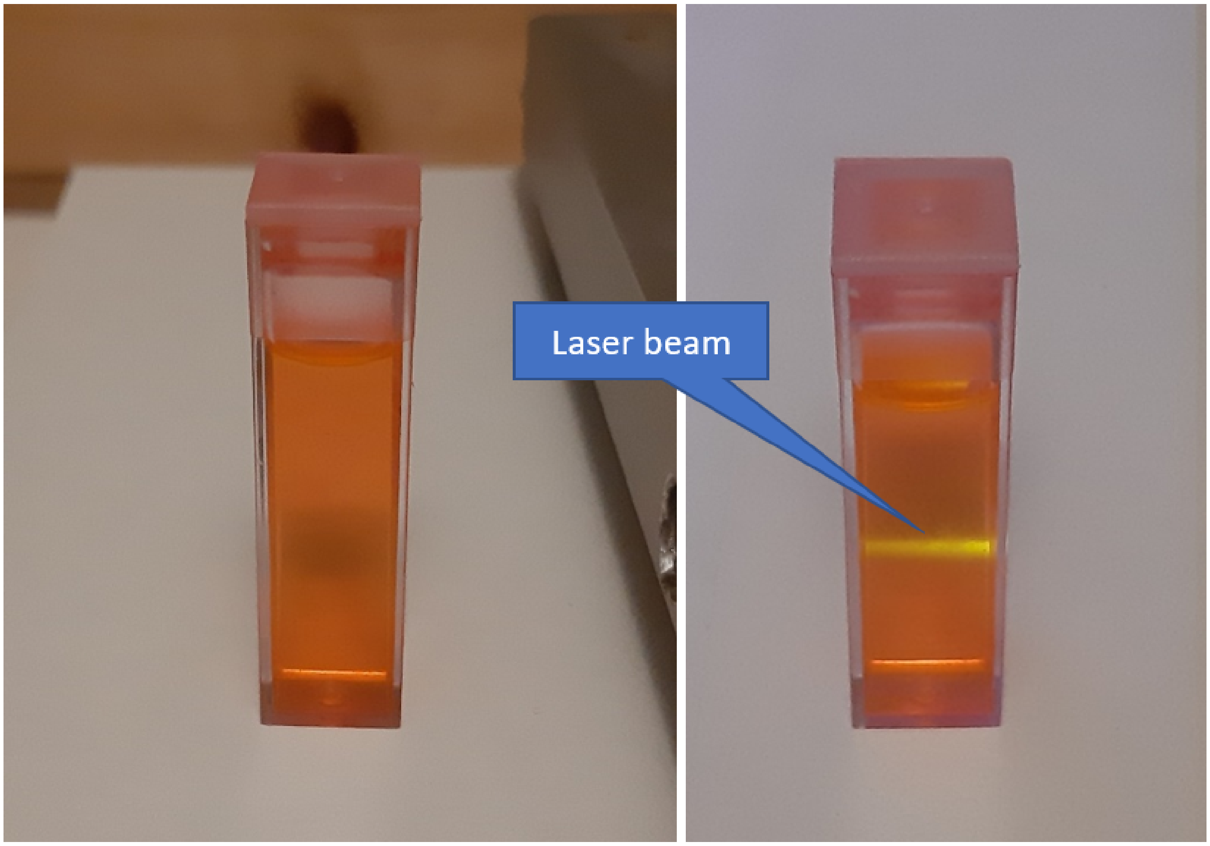
After assembling the laser it's time to make it work and it's not easy. It is necessary to position the electrodes so that they are flat, parallel and equally spaced, the distance between the electrodes is around 2-3mm. The right conditions allow the establishment of a homogeneous discharge along the whole laser channel, at low brightness, with few electric arcs. However, it must be said that in a free atmosphere at normal pressure it is almost impossible to completely eliminate the small arcs that form along the electrodes. The image below shows a photograph of our discharge : as you can see it is extended along the entire channel even if there are several hot spots.



The laser emission takes place in the ultraviolet range and therefore it is not normally visible, to check the presence of the laser pulse you can for example use a paper screen with a highlighter : the laser pulse will give rise to a fluorescent green spot, such as shown in the figure below.



Alternatively, an organic dye in solution (e.g. rhodamine or coumarin) can be used : the passage of the laser pulse through the solution will give rise to a fluorescent line as shown in the images below.



Safety Remarks

The nitrogen laser we have described involves the use of a high voltage generator and, during set-up and operation, different parts of the instrument are at high potentials (~5-10KV) and therefore **dangerous**. We recommend the use of a battery-powered low-power generator and the use of a discharger to be used after turning off the laser to discharge the capacitors. Recall that the capacitors can maintain even for hours a quantity of charge sufficient to cause painful discharges. Needless to say, all adjustments (spark gap and electrodes) must be made with the equipment off.

It is also recommended not to look directly at the laser beam, to protect the eyes from the UV radiation produced by the discharges, to use hearing protection and to pay attention to the handling of the permanent magnets.

Conclusions

The TEA nitrogen laser in free atmosphere is one of the simplest lasers, certainly within the reach of a “maker”. However, there are many “details” that must be treated carefully otherwise you risk spending a lot of time seeing it “not working”. In the project that we proposed in this article we have adopted some solutions that have simplified our construction and adjustment : the iron ground base plate has allowed us to use magnets, the U-shaped guides with plastic screws help in adjusting and fixing the electrodes, the brass electrodes are more rigid than the aluminum ones and therefore maintain more linearity.

The next steps could be the use as a pumping laser for a dye laser and the adoption of a low pressure nitrogen discharge channel in order to increase the pulse power.