Modeling of Nitrogen Laser

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In Partial Fulfillment of the Requirement for
the Degree of Master of Science in Physics

By

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The undersigned hereby certify that they have read and recommend to the School of Graduate Studies for acceptance a thesis entitled "**Modeling of Nitrogen Laser**" by **Melak Gedefe** in partial fulfillment of the requirements for the degree of **Master of Science in Physics**.

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Abstract

A model for the pulsed nitrogen laser is proposed and a scaling parameters are identified so as to enable to study a laser over its range of discharge modes. This result is explained for the critically damped case and the more typical case of damping factor of 0.4. The analysis shows that in a typical nitrogen laser the rate of rise of nitrogen lase gap voltage $\frac{dV_g}{d\tau}$ prior to laser breakdown is $\frac{0.5KV}{ns}$ and experiment reported in the literature suggests that $\frac{dV_g}{d\tau}$ is required for uniform breakdown across the laser gap as a pre-requisite for good lasing action

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Above all, I would like to thank the almighty; God, for letting me to accomplish this stage. I would like to express my deepest gratitude and respect to my advisor and instructor Prof.Gholap for his guidance, assistance, supervision and contribution of valuable suggestions and overly enthusiasm.

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Chapter 1

Introduction

1.1 Brief history and review of nitrogen laser

The nitrogen laser is a gas laser based on the chemical stable molecular species, N_2. The first nitrogen laser produced only a few watts, but soon researchers began to optimize them. The nitrogen laser emits short pulse at high repetition rates. Repetition rate exceeding 100Hz can be obtained if great care is taken in design of electrodes, high voltage circuitry and spark gap switch.

Pumping is achieved using an electrical discharge, exited transversely in a tube through which N_2 at a pressure of about 100 Torr [in the case of law pressure nitrogen laser] to one atm and above [in the case of TEA nitrogen laser] is following the excitation rate by the direct electron impact for the transition $X \rightarrow C$ is much longer than that for $X \rightarrow$B. However, the life time of the state C is only about a maximum of 40 ns (at a pressure down to about 40 Torr),where as the corresponding value for state B is about $10\mu s$. Note that the lower lasing level has longer life time than that of the upper. Hence we have to over come one big problem if we insist to use N_2 as an active medium of the laser. What is this big problem and how can we over come it ? it is obvious that the lower level of lasing transition has a longer life time than that of the upper, then lasing action may not be possible at all, or might be possible only in pulsed mode. This is the situation with nitrogen laser and (also with a few other lasers, such as the copper vapor laser). In such laser the upper lasing level should be preferentially filled quickly, by a pulsed discharge of 100s of Ampere or more. It is only when the upper level can filled very quickly and population inversion can be achieved, lasing action will take place in the case of nitrogen laser 1-10ns after the lasing action begin, the lower energy level B tends to fill up with molecules (and stay that way since its life time is much longer) this effect the laser action to cease for a time at least equal to the natural radiative life time of level B, which is about 10μs. In reality it will take much longer time before the next lase action takes. It is informative here to note this self terminating effect seriously limits both the pulse repetition frequency and efficiency of nitrogen laser.

The realization of lasing action in N_2 second positive system was reported by H.G Heard in 1963 [12] only 3 years after the first successful operating laser, the ruby laser, was invented by Maiman [21] Heard has seen that the second positive system of N_2 (i.e $C^3\Pi_u \rightarrow B^3\Pi_g$) at 337.1nm to be in stimulated emission, and the theory of the pulsed nitrogen system has been considered by Ali et.al [13].A general rate equation analysis for three level ultraviolet system has been only done by Elton et.al [14]

. The transition $C^3\Pi_u \rightarrow B^3\Pi_u$ of N_2 is an example established by the lower state of the transition electron collision. Superradiant oscillation has been observed, on this transit at power level in excess of 2MW for pulse of length of 10ns. The calculation [18] indicates that the preferential excitation of the nitrogen $C^3\Pi_u$ state is $\sim \Pi a_0$ is near 15ev. Since the lower state of the transition is metastable on the time scale of interest, a rapid raising high $\frac{e}{p}$ discharge is required, in addition to direct excitation by collisions, refined the theoretical treatment of the nitrogen second positive system have included the effect of collisional ionization of the state $C^3\Pi_u$ [18] finally we observe that N_2 second positive band occurs in the triple manifold of states, where as the ground $X_1 \sum_g^+$ state of N_2 is singlet configuration. This suggests that exchange processes are involved in excitation scheme of this system.

1.2 Background

Since its invention,the field of nitrogen laser has undergoing a rapid and extensive development. Various modification on the original version, reported by Leonard [10], Gerry [18] and Shipman [19],we have been made by numerous other researchers. Most of the information available from this publication more less deal with constructive details. They also describe the dependence of the laser out put on different parameters, such as the gas pressure in the laser tube, the spark gap inductance, the characteristics impedance of transmission line, the charging voltage and the nature of driving electrical circuit, efficient operation of pulsed gas laser having very short upper state life times depends strongly on the property of the discharge circuit, therefore it can be sayed , many papers have been published on the optimization of the energy transfer from source to the laser channel.

Where as the time history of the laser pulse is well known, little information is available on the switching property of trigged spark gaps using fast current switches and the characteristics of the transmission line coupling the switch to the laser channel for optimum out puts, the other objective of this research can be put in the following way. To the knowledge of the researcher no experimental and theoretical study of nitrogen laser in particular, and laser in general has been made in Ethiopia. However it is learnt that the need for their use specially in different laboratories, for laser based spectroscopy is growing from time to time. Parallel to this growing demand the cost of this commercial lasers is increasing at times it is unfavorable, one way to over come this problem, and probably the best means is to develop home built lasers using locally available materials. It is hoped that researcher effort in this area will be increased in the future. Laser vary in complexity from simple home built nitrogen laser which requires only a pulsed 20kv power supply, a couple of electrodes and small supply of nitrogen gas to generate 100kwatts of UV light at 337.1nm in a few nanosecond flashes to, the very elaborate very high power multi beam line system used in fusion studies and in matter compression.

In addition to its relative simplicity of construction, the nitrogen laser is one of the most useful because of its effectiveness as a pump for tunable dye laser and this combination is particularly powerful because it open ups the possibility of relative and extensive laser based spectroscopy. It should be prudent therefore for any researcher interested embarking on a program of laser based research and development to start by building a nitrogen laser and then to use it to pump.

1.3 Objective

✓ Studying parameters of nitrogen laser.

✓ Establishing the experimental value of nitrogen laser operating voltage for the uniformity of discharge through the laser circuit.

1.4 Justification

The transversally excited pulsed nitrogen laser depend for its operation on two important requirements

(I). a uniform discharge occurring throughout the length of the discharge channel this uniformity depend on a sufficiently high rate of voltage $\frac{dV_g}{dt}$ across the laser gap

(II). a sufficiently high rate of energy absorption in the laser gap plasma during the main discharge

Whilst the second requirement is generally well known since population inversion has to be achieved in a time shorter than the relevant transition life time of 40ns the first requirement of a minimum $\frac{dV_g}{dt}$ is not well known. This requirement may seen in the following way.

The laser channel consists of two long parallel placed electrodes forming a constant gap of about 1cm along the whole length $\sim 50cm$ the gap is about 100Torr of nitrogen. Although the gap may be set at a uniform spacing, local irregularities exist and at any given times the breakdown voltage across will vary if only by a small amount from point to points along the gap. If such a gap is subjected to start rising voltage difference across it i.e, $\frac{dV_g}{dt}$ is small then when the voltage difference becomes sufficient to breakdown at that point of the gap which happens to have the slowest voltage at that given time ,the gap will break down at that point a soon as that point breakdowns, a pulse of zero voltage will traverse the length of the gap at the speed of electromagnetic wave, thus, stopping any further breakdown except at the first point of breakdown .

However, an infinitively fast rising pulse is applied i.e,$\frac{dV_g}{dt} \rightarrow \infty$,then after the first point break down and as the pulse of zero voltage traverse away from the point of break down the other points also break down because before the pulse of zero voltage arrives, these points have already been stressed to breakdown be breakdown by the infinitively rising voltage pulse, it may be seen from this argument that for uniform break down the rate of rise of gap voltage $\frac{dV_g}{dt}$ must be such that the point (in the gap) with the highest breakdown voltage(due to surface difference) rise to this breakdown voltage before the pulse of the zero voltage arrives from the first breakdown point. Thus, there is in general a minimum $\frac{dV_g}{dt}$ for uniform break down. This value will of course depend on uniformity of gap spacing and electrode surface conditioning. In general again ,however, nitrogen laser gaps will have been built to a high standard of uniformity of gap setting and gap surface conditioning. It then remains to be seen if a minimum $\frac{dV_g}{dt}$ may be experientially observed to be required for good uniformity. To help answer this question a lumped parameter model for the nitrogen laser circuit is given. In the present work the circuit equation are written with greater details and are non-dimensional so that the scaling parameters can identified. The scaling parameters are then varied to cover a wide range of operation of the nitrogen laser The computations are used to determine the rate of rise of laser gap voltage $\frac{dV_g}{dt}$ and the rate of energy absorption at laser gap as function of the scaling parameters.

1.5 Spark gap

A spark gap consists of an arrangement of two conducting electrodes separated by a gap usually filled with a gas such as air, designed to allow an electric spark to pass between the conductors. When the voltage difference between the conductors exceeds the gap's breakdown voltage, a spark forms, ionizing the gas and drastically reducing its electrical resistance. An electric current then flows until the path of ionized gas is broken or the current reduces below a minimum value called the 'holding current'. This usually happens when the voltage drops, but in some cases occur when the heated gas rises, stretching out and then breaking the filament of ionized gas. Usually the action of ionizing the gas is violent and disruptive, often leading to sound (ranging from a snap for a spark plug to thunder for a lightning discharge), light and heat. Spark gaps were used historically in early electrical equipment, such as spark gap radio transmitters, electrostatic machines, and x-ray machines. Their most widespread use today is in spark plugs to ignite the fuel in internal combustion engines, but they are also used in lightning arrestors and other devices to protect electrical equipment from high voltage transients.

Triggered Spark Gaps

Triggered spark gaps are very popular as fast high current switches. With proper design, a triggered spark gap can switch megawatts of power in a few microseconds, with jitters(is the time variation of a periodic signal in electronics and telecommunications, often in relation to a reference clock source) of less than a nanosecond. These devices make use of the very low impedance of an arc once the arc is established. Two electrodes are separated by sufficient distance that the gap doesn't spontaneously break down. The breakdown is initiated by a variety of means: UV irradiation from another spark or a laser, an over-voltage pulse, or reducing the gas pressure in the gap.

There is a lot of similarity to a xenon flash tube here. In a triggered spark gap, the idea is to switch a lot of current at high voltage, so the arc characteristics are optimized for that. In a flash tube, the idea is to generate light, so the design is optimized for that (i.e. use xenon (high lumens/watt), a long path (limit watts/volume), etc).

Chapter 2

Energy Level Diagram of Nitrogen laser

2.1 Population inversion of nitrogen laser

The molecular nitrogen laser at 337.1nm was first demonstrated in 1963, and has been commercially available since 1972. They rarely show up in laboratories though, as they have been largely surpassed by Excimer lasers and third or fourth harmonic light from neodymium lasers, that have higher powers and 'cleaner' beams than nitrogen lasers. The TEA(transverse electrical discharge in gas at atmospheric pressure)nitrogen gas laser produces intense, short, pulses of UV radiation at 337.1nm. No vacuum pump is required as the laser operates at atmospheric pressures however the electrical discharge circuitry must be extremely fast in order for this laser to work.

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. When these electrons decay back down to their ground state a photon is emitted that has an energy (E=$h\times$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.

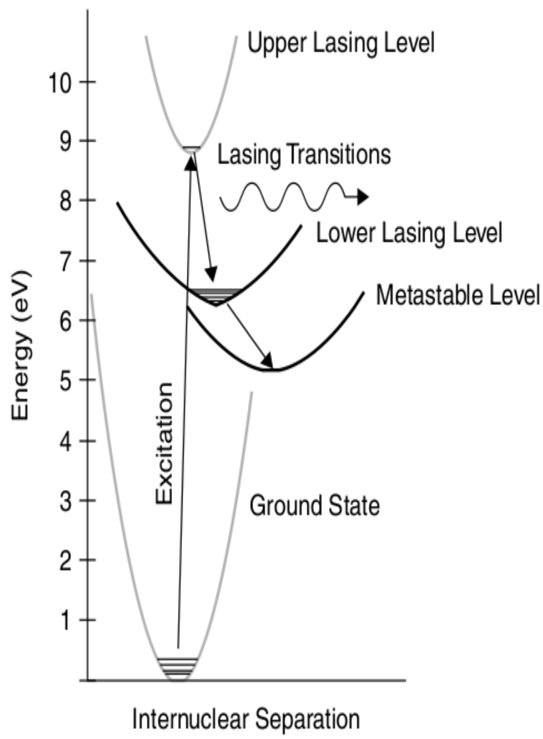

Figure 2.1: Energy level of molecular nitrogen laser

The energy levels of the nitrogen molecule as they apply to this laser are outlined in Fig 2.1. Each level shown is actually a series of vibrational levels dependent on internuclear separation. The laser begins when a nitrogen molecule is excited by direct collision with electrons in the discharge to enter the ULL(upper lasing level). From the ULL the molecule falls to the LLL(lower lasing level) emitting a photon of UV(ultraviolet) light in the process. Transitions in a normal nitrogen laser operating at 337.1nm

After emitting a photon in the lasing transition, the molecule then falls to a metastable state and finally, to the ground state. Although not a four-level laser in the proper sense (the system lacks a pump level since the ULL is pumped by direct electron collision), it is certainly not a three-level system since it does feature a distinctLLL. In this respect the system resembles that of a copper-vapor laser with the inclusion of a metastable state. The gain medium is nitrogen molecules in the gas phase. The nitrogen laser is a 3-level laser. In contrast to a ruby laser or to other more typical 4-level lasers, the upper laser level of nitrogen is directly pumped, imposing no speed limits on the pump. Pumping is normally provided by direct electron impact; the electrons must have sufficient energy, or they will fail to excite the upper laser level. Typically reported optimum values are in the range of 80 to 100eV per Torrcm pressure of nitrogen gas.

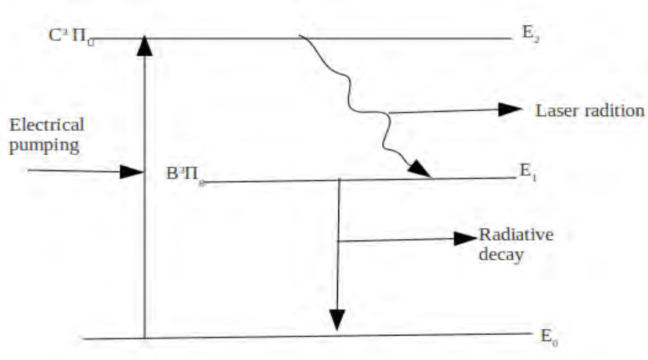

Figure 2.2: Nitrogen laser pumping scheme

2.2 Nitrogen laser structure

2.2.1 Blumlein transmission line

The basic requirement for a practical nitrogen laser is to supply a massive electrical current (i.e., a huge quantity of electrons) with a fast rise time and short pulse length to excite the gas. To achieve this, most nitrogen lasers use an electrical configuration called a Blumlein configuration, which generates a massive over-voltage of the laser channel (and subsequent large current through the lasing gas) with a rise time of nanoseconds. A Blumlein configuration is shown schematically in Figure 2.3, where we find two capacitors essentially in parallel separated by the laser channel itself. Both capacitors charge simultaneously through the charging inductor (which offers little electrical resistance to the charging current) until the spark gap fires when the break- down voltage is reached (typically, about 15 kV for a small laser). In simplest form, a nitrogen laser may operate as a relaxation oscillator, repeatedly charging and firing; the use of triggered spark gaps or thyratrons allows the laser to be triggered as required. The gap now conducts essentially short-circuiting C_1 and draining charge from it, making the top terminal of C_1 negative. A massive voltage difference appears quite suddenly across the laser gap since the left side of the tube is now negative and the right side still positive. Charge from C_1 flows across the laser channel as a pulse of very high electrical current, in many cases thousands of amperes.

The electrical dynamics of the laser are not as simple as a discharge, since the laser tube has long transverse electrodes over which the high current must be distributed. With a short discharge time necessitated by the short upper lasing-level lifetime, the laser is best excited by a traveling electrical wave which starts at the rear of the laser and moves forward at the speed of light exciting nitrogen molecules as it progresses. To accomplish this, capacitors are fabricated as long, distributed capacitances parallel to the laser tube. The initiating spark gap is placed at

the rear of one capacitor so that the electrical pulse begins at the rear of the laser first and travels toward the front of the laser. In many cases it is possible to design the laser as a transmission line for efficient transfer of electrical energy into the lasing volume. The sequence of events during firing of the laser is outlined in Figure 2.4 In this particular

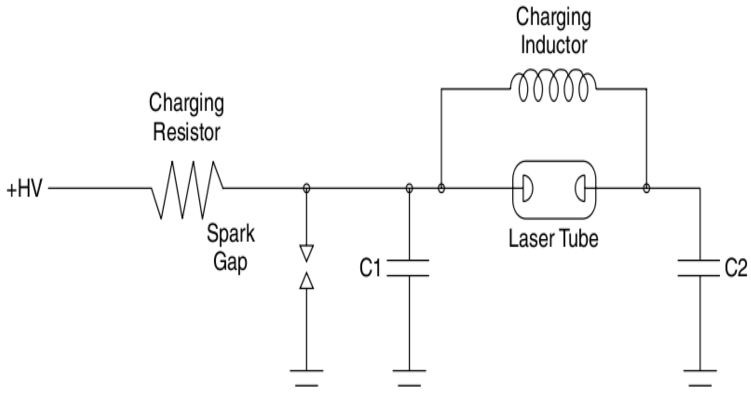

Figure 2.3: Electrical schematic of a Blumlein laser

design, common for small laboratory-type nitrogen lasers, the capacitors are fabricated on an epoxy glass substrate. Two capacitors are formed with copper foil on the top of the board (there is a separation between the two capacitors underneath the laser tube, so they are not visible in the figure), and the bottom of the board is the common terminal for both. The spark gap that initiates electrical discharge is mounted on the left capacitor near the rear of the laser. In the simplified figure (in which details such as the charging inductor are omitted for clarity) both capacitors are charged to a high voltage equally,so no voltage difference appears across the laser channel. As the capacitors are charged, the voltage across the capacitors as well as the spark gap rises until breakdown occurs (in Figure 2.4b) and the spark gap conducts. Charge can be visualized in the figure as moving toward the spark gap in an arc centered around the spark gap. No voltage appears across the laser channel until the charge at the rear of the left capacitor for the laser has been drained and a voltage differential appears at the rear of the laser channel. The discharge in the laser thus begins here. As the traveling wave in the capacitor spreads, the voltage differential travels toward the front of the laser channel at the speed of light, generating a discharge that also travels toward the front of the laser. Light emission follows the discharge and a beam emerges from the laser. A practical nitrogen laser based on this design is seen operating in the authors laboratory in Figure 2.5 The initiating spark gap is visible in the upper-left corner. It emits an intense flash of light since high currents pass

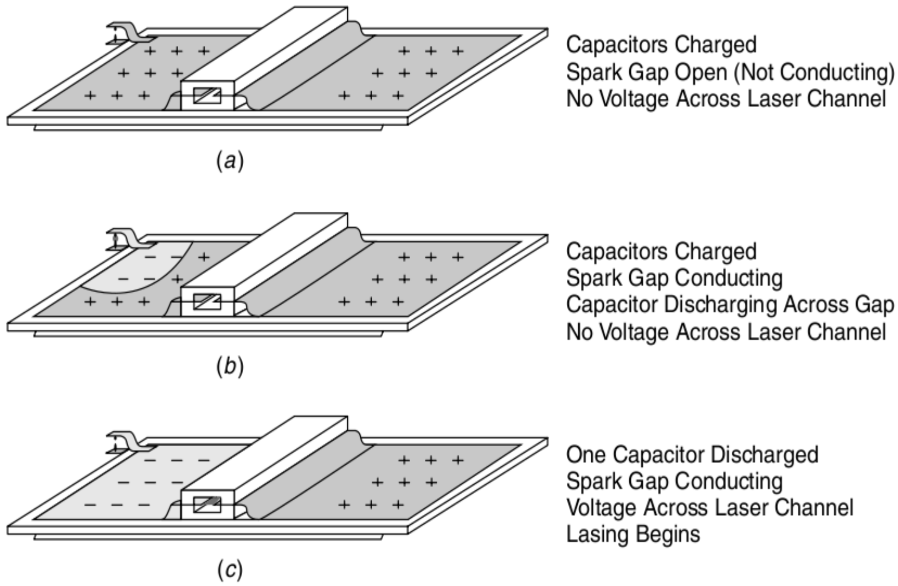

Figure 2.4: Nitrogen laser discharge sequence

through it. As well as the gap, other visible features include the charging inductor, which bridges the laser tube and the charging resistor near the spark gap. This is a flowing-gas laser in which nitrogen gas under low pressure flows slowly through the tube. A needle valve used to regulate flow is also seen in the lower left of this laser. After initiation of laser action by the spark gap and discharge through the laser channel, the laser pulse is generated and will continue until population inversion ceases. Laser action ceases regardless of how long the electrical pulse lasts, so it is pointless to design a laser with a longer discharge time than this. This parameter determines the size of the capacitors employed in the laser.

The nitrogen laser may operate at atmospheric pressures in TEA configuration as well as at low pressure(generally, 20 to 60 Torr). These lasers are physically similar to the low pressure types and most use a Blumlein configuration. In the case of a TEA nitrogen laser, though, the lifetime of the ULL decreases to about 2.5 ns.4 The requirements for a fast

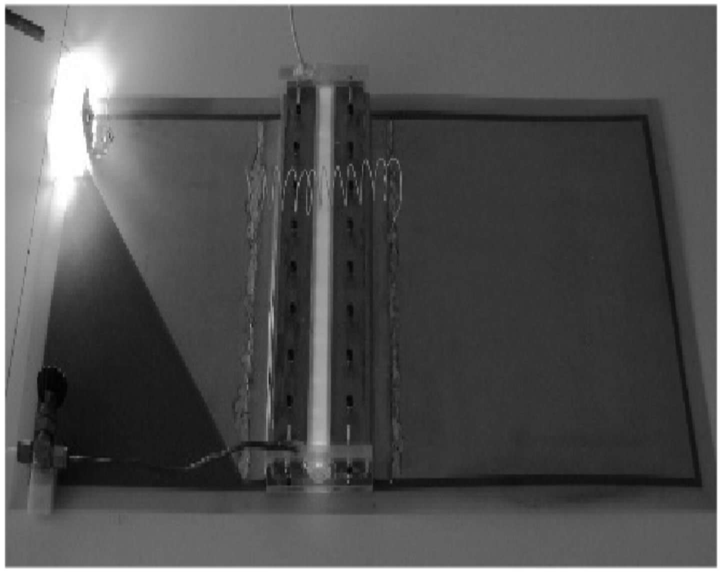

Figure 2.5: Practical nitrogen laser.

discharge are even more pronounced in a TEA laser, which must be constructed to keep inductances in the discharge path to an absolute minimum. With this in mind, dielectrics for capacitors are kept very thin (since the intrinsic inductance of a transmission-line capacitor is proportional to the thickness of the dielectric) and the laser channel is mounted directly on top of the capacitors. A practical TEA laser is pictured in Figure 2.5, in which the spark gap is located in the upper-right corner of the photo and the long transverse electrodes are visible down the center of the laser. The laser pictured operates using open air as the lasing gas. This is possible since air is 78% nitrogen, although output power decreased by 80% over the use of pure nitrogen gas. A possible source of inefficiency is evident in that the discharge reveals hot spots or arcs. Unlike the low-pressure laser, which features a consistent and even discharge between the electrodes, discharges in TEA lasers tend to concentrate and resemble individual sparks. For efficiency, measures must be taken to even out the discharge, including dilution of the nitrogen gas with helium, use of an electrode structure consisting of multiple points, and preionization of the discharge channel with a high-voltage corona or ultraviolet radiation before the main laser discharge ensues.

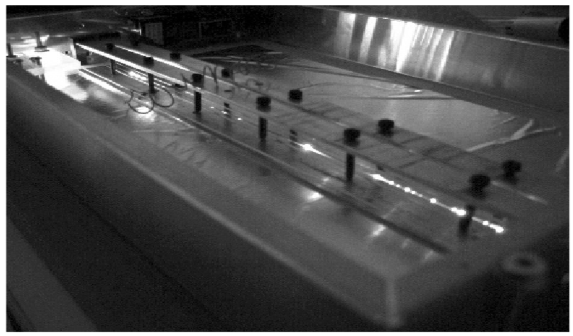

Figure 2.6: TEA Nitrogen laser

Most small commercially available nitrogen lasers use spark gaps for their simplicity. These spark gaps are filled with nitrogen gas for reliable, predictable firing. In the case of a TEA laser, the gap may be placed inside the same pressure vessel as the rest of the laser. Filling with nitrogen also eliminates the objectionable production of ozone when the gap fires. In some larger lasers, thyratrons are used instead of spark gaps. Thyratrons are switching devices that use mercury vapor or hydrogen gas and feature incredibly fast rise times, many times faster than spark gaps. As well as faster switching times, thyratrons also allow triggering on command instead of simply triggering when the spark gap is over voltage, an important feature when this laser is used in a laboratory experiment requiring synchronization and precise timing.

Because of the low inductance discharge path required, essential elements of the nitrogen laser, such as storage capacitors and switches (thyratrons or spark gaps), are an integral part of the laser itself. To charge the capacitors, a basic high voltage supply is required, the supply current of this supply limiting the maximum firing rate for the laser. Designs for high-voltage power supplies vary from simple neon-sign transformers to efficient and compact switching power supplies. These supplies are usually housed in the main laser housing for safety. In many low pressure nitrogen lasers, gas flows continually through the lasing channel. This helps to eliminate impurities generated during the discharge as well as cool the laser. Gas flow is quite slow, so consumption is minimal. Many small commercial nitrogen lasers are of the TEA variety and use a sealed laser channel, so a gas supply and vacuum pump are not required, making a much simpler laser for laboratory use. With a fast enough discharge time, some low pressure nitrogen lasers can also operate using hydrogen gas (with a transition in the extreme UV at 160 nm) or neon gas (with a visible transition at 540.1 nm). Both of these alternatives have shorter upper-level lifetimes than nitrogen does, so an extremely fast laser discharge is required (much faster than normally required in a nitrogen laser). Another alternative is the use of a carbon dioxide gas mixture consisting of helium, nitrogen, and carbon dioxide. With suitable optics the laser operates as a TEA laser, producing fast, short pulses of light at 10.6 mm in the infrared.

2.3 Prototype Design

The TEA laser resembles the low-pressure nitrogen laser in design with the exception that the entire transmission line must be optimized for a much faster discharge. The figure below outlines the cross section of the laser which may be compared that of the low-pressure nitrogen laser.

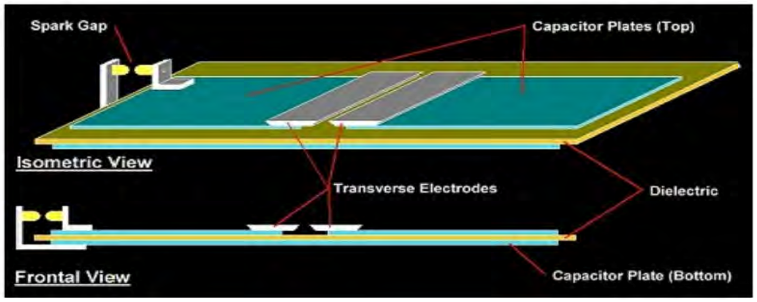

Figure 2.7: Cross section of the prototype laser

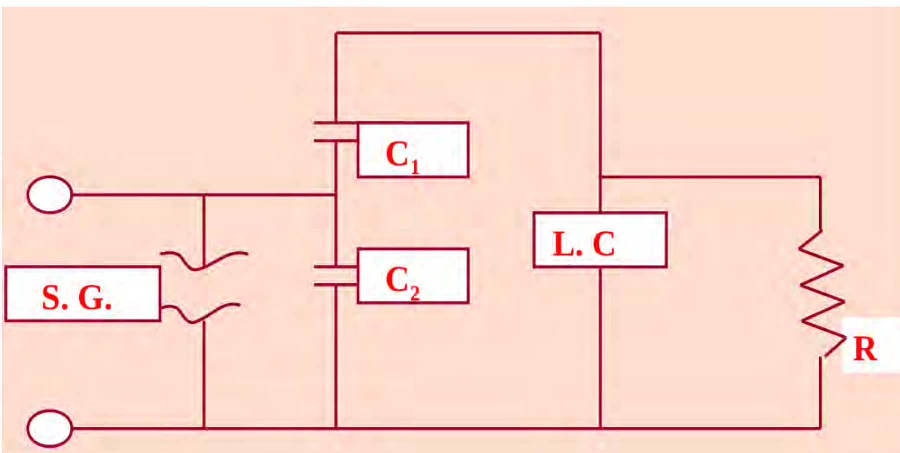

Figure 2.8: Transfer of Capacitance

2.4 Out put characteristics

Beam quality is poor in a nitrogen laser. Being a super-radiant laser with enormous gain, the output really consists of highly amplified spontaneous emission. In a lower-gain laser, photons traverse the cavity many times, stimulating the emission of many more photons of exactly the same wavelength. In a nitrogen laser, photons often make only one pass through the amplifier before exiting. Collimation is hence poor and divergence is quite large compared to other types of lasers. Coherence length is also poor, since the spectral width of the laser output is quite wide. line operation.

2.5 Laser system

laser is acronym for Light Amplification by Stimulated Emission of Radiation. Optical electronic device that generates an intense (very narrow) beam of single color (monochromatic) light by pumping (amplifying) photons with more energy through collisions with other photons. Laser beams can travel vast distances without dispersion and can carry enormous amounts of energy (100 million watts per square centimeter, and more). Different types of lasers are used for for different purpose ;
→Medical Uses of Lasers The highly collimated beam of a laser can be further focused to a microscopic dot of extremely high energy density. This makes it useful as a cutting and cauterizing instrument. Lasers are used for photo-coagulation of the retina to halt retinal hemorrhaging and for the tacking of retinal tears. Higher power lasers are used after cataract surgery if the supportive membrane surrounding the implanted lens becomes milky. Photo-disruption of the membrane often can cause it to draw back like a shade, almost instantly restoring vision. A focused laser can act as an extremely sharp scalpel for delicate surgery, cauterizing as it cuts. ("Cauterizing" refers to long-standing medical practices of using a hot instrument or a high frequency electrical probe to singe the tissue around an incision, sealing off tiny blood vessels to stop bleeding.) The cauterizing action is particularly important for surgical procedures in blood-rich tissue such as the liver.
→Welding and Cutting]

The highly collimated beam of a laser can be further focused to a microscopic dot of extremely high energy density for welding and cutting. The automobile industry makes extensive use of carbon dioxide lasers with powers up to several kilowatts for computer controlled welding on auto assembly lines. Garmire points out an interesting application of CO2 lasers to the welding of stainless steel handles on copper cooking pots. A nearly impossible task for conventional welding because of the great difference in thermal conductivities between stainless steel and copper, it is done so quickly by the laser that the thermal conductivities are irrelevant. Lasers have been used to make incisions half a micron wide, compared to about 80 microns for the diameter of a human hair.

→Surveying and Ranging Helium-neon and semiconductor lasers have become standard parts of the field surveyor's equipment. A fast laser pulse is sent to a corner reflector at the point to be measured and the time of reflection is measured to get the distance. Some such surveying is long distance! The Apollo 11 and Apollo 14 astronauts put corner reflectors on the surface of the Moon for determination of the Earth-Moon distance. A powerful laser pulse from the MacDonald Observatory in Texas had spread to about a 3 km radius by the time it got to the Moon, but the reflection was strong enough to be detected. We now know the range from the Moon to Texas within about 15 cm, a nine significant digit measurement. A pulsed ruby laser was used for this measurement.

→Lasers in the Garment Industry

Laser cutters are credited with keeping the U.S. garment industry competitive in the world market. Computer controlled laser garment cutters can be programmed to cut out 400 size 6 and then 700 size 9 garments - and that might involve just a few cuts. The programmed cutter can cut dozens to hundreds of thicknesses of cloth, and can cut out every piece of the garment in a single run. The usefulness of the laser for such cutting operations comes from the fact that the beam is highly collimated and can be further focused to a microscopic dot of extremely high energy density for cutting.

→Lasers in Communication

Fiber optic cables are a major mode of communication partly because multiple signals can be sent with high quality and low loss by light propagating along the fibers. The light signals can be modulated with the information to be sent by either light emitting diodes or lasers. The lasers have significant advantages because they are more nearly monochromatic and this allows the pulse shape to be maintained better over long distances. If a better pulse shape can be maintained, then the communication can be sent at higher rates without overlap of the pulses. Ohanian quotes a factor of 10 advantage for the laser modulators. Telephone fiber drivers may be solid state lasers the size of a grain of sand and consume a power of only half a milliwatt. Yet they can sent 50 million pulses per second into an attached telephone fiber and encode over 600 simultaneous telephone conversations (Ohanian).

→Heat Treatment

Heat treatments for hardening or annealing have been long practiced in metallurgy. But lasers offer some new possibilities for selective heat treatments of metal parts. For example, lasers can provide localized heat treatments such as the hardening of the surfaces of automobile camshafts. These shafts are manufactured to high precision, and if the entire camshaft is heat treated, some warping will inevitably occur. But the working surfaces of the cams can be heated quickly with a carbon dioxide laser and hardened without appreciably affecting the remainder of the shaft, preserving the precision of manufacture.

Chapter 3

Damping and Natural Response of Nitrogen Laser RLC Circuit

It is worthwhile to note that laser circuit consists of Blumlein transmission line and the laser channel. When this laser channel breaks down there is a pressure which is mainly inductive with a very small resistance

. Thus,we may say that the circuit consists of resistance, inductance and capacitance. Here let us consider consider a series RLC simple circuit with a constant voltage. The current equation for the circuit is

$$\frac{Ldi}{dt} + Ri + \frac{1}{C}\int idt = v \tag{3.0.1}$$

$$\Rightarrow \frac{Ldi}{dt} + Ri + \frac{1}{C}q = v \tag{3.0.2}$$

differentiating we have

$$L\frac{d^2i}{dt^2} + R\frac{di}{dt} + \frac{i}{C} = 0 \tag{3.0.3}$$

This is the second order linear homogeneous equation

The corresponding auxiliary equation is

$$LM^2 + RM + \frac{1}{C} = 0 \tag{3.0.4}$$

$$M_1 = \frac{-R}{2L} + \frac{\sqrt{(R^2 - 4L/C)}}{2L} \tag{3.0.5}$$

$$= -\alpha + \sqrt{\alpha^2 - \omega_0^2} \tag{3.0.6}$$

$$M_2 = \frac{-R}{2L} - \frac{\sqrt{(R^2 - 4L/C)}}{2L} \tag{3.0.7}$$

$$= -\alpha - \sqrt{\alpha^2 - \omega_0^2} \tag{3.0.8}$$

where $\alpha = R/2L$ is called the damping coefficient of the circuit $\omega_0 = \sqrt{1/LC}$ is the resonance frequency of the circuit.

There are three possibilities

between R,L and C

. case 1 when $R^2 > \frac{4L}{C}$ (over damped)

Here both m_1 and m_2 are real distinct and negative.

the general solution is given by

$i(t) = Ae^{m_1 t} + Be^{m_2 t}$

Here the current is not oscillatory and the vibration returns to equilibrium

case 2 when $R^2 = \frac{4L}{C}$

Here the roots are negative, real and equal i.e $m_1 = m_2 = -R/2L$ (critically damped)

The general solution is given by

$i(t) = (A + Bt)e^{-Rt/2L}$

The current here returns to equilibrium in the minimum time and there is just enough damping to prevent oscillation

case 3 when $R^2 < \frac{4L}{C}$ (undamped)

Here the roots are complex where

$m_1 = \alpha + j\omega$, $m_2 = \alpha - j\omega$

The general solution is given by

$i(t) = e^{\alpha t}(Acos\omega t + Bsin\omega t)$, $\omega = \sqrt{(\frac{1}{LC} - \frac{R^2}{2L^2})}$ In this case the current is oscillatory and the amplitude decrease exponentially,bounded by $i = \pm\sqrt{A^2 + B^2}e^{-Rt/2L}$

A typical nitrogen laser circuit may be represented by the fast parallel plate capacitors C_1 and C_2 with very low inductance L_1 and L_2 are charged to voltage V_0 and connected to the laser gap represented by a resistance r_g and inductance L_{go} as shown in the diagram. The inductance L_{g1} and L_{g2} represent the channel inductance on either side of the laser gap. The capacitor C_2 is connected to an external spark gap represented by r_e in the diagram and with inductance L_e. The external spark gap resistance r_e ,which is very small owing to the pressure created by the discharge therefore the external circuit $L_2 - L_e - r_e - C_2$ is fairly oscillatory; whilst for good and fast energy transfer one would hops to design for r_g to have such a value that the laser discharge circuit i.e $C_1 - L_1 - L_{g1} - r_g - L_{go} - L_{g2} - L_2 - C_2$ should be critically damped. However one would expect that typically this latter circuit would be less than critically damped

When the external spark gap switches at $t = 0$, the voltage V_2 drops from its initial value V_0, swings negative towards V_0 with a time constant given by $\sim \sqrt{L_e C_2}$ since $L_e >> L_2$, thus providing a rate of rise of gap voltage in the order of $\frac{2V_0}{\sqrt{L_e C_2}}$ which if sufficient should cause the laser gap to not only breakdown but,breakdown uniformly at time $t = t_s$. The main discharge between C_1 and C_2 should then occur with a short time constant $\sim \sqrt{(L_1 + L_2 + L_g)}\ \frac{(C_1 C_2)}{(C_1 + C_2)}$, Where $L_g = L_{g1} + L_{g2} + L_{g0}$ modulated with a slower discharge with time constant $\sqrt{L_e}(C_1 + C_2)$ which subsequently removes all the stored energy through the external spark gap r_e. The equation describing the discharge sequence are as follows: For $0 \leq t \leq t_s$ (before laser gap breaks down):

$$I_L = 0, \tag{3.0.9}$$

$$L_2 \frac{dI_e}{dt} + L_e \frac{dI_e}{dt} + r_e I_e = V_0 - \frac{\int I_e dt}{c_2}. \tag{3.0.10}$$

I_L=laser circuit current, I_e=external circuit current, with initial conditions:

t=0,

$I_e = 0$, $\int I_e dt = 0$, $\frac{dI_e}{dt} = \frac{V_0}{L_2+L_e}$

For $t > t_s$ (after laser gap breaks down) equation(3.0.9) and equation(3.0.10) are replaced by

$$L_2\frac{dI_e}{dt} - L_2\frac{dI_L}{dt} + L_e\frac{dI_e}{dt} + r_eI_e = V_0 - \frac{\int I_e dt}{c_2} + \frac{\int I_L dt}{c_2} \tag{3.0.11}$$

and

$$L_1\frac{dI_L}{dt} + (L_{g1} + L_{g2} + L_{g0})\frac{dI_L}{dt} + L_2\frac{dI_L}{dt} - L_2\frac{dI_e}{dt} + r_gI_L = V_0 - \frac{\int I_L dt}{c_1} - V_0 - \frac{\int I_L dt}{c_2} + \frac{\int I_e dt}{c_2} \tag{3.0.12}$$

At the moment of laser the gap breaks down i.e, $t = t_s$ the value of I_e, $\int I_e dt$, $\frac{dI_e}{dt}$ are known from the numerical integration of the above equations

$t = t_s$, $I_L = 0$, $\int I_L dt = 0$, and

$$\{\frac{dI_L}{dt}\}_{t_s} = \frac{\{\frac{\int I_e dt}{c_2}\}_{t_s} + \{L_2\frac{dI_e}{dt}\}_{t_s}}{L_1 + L_2 + L_g} \tag{3.0.13}$$

NORMALIZATIONS

The normalization of the above equations at $t = 0$, is accomplished by putting: $\tau = \frac{t}{t_0}$, $\iota_e = \frac{I_e}{I_0}$, $\iota_L = \frac{I_L}{I_0}$

where $t_0 = \sqrt{L_2C_2}$ and $I_0 = \frac{V_0}{\sqrt{(L_2/C_2)}}$

The equation (3.0.10) given below

$$L_2\frac{dI_e}{dt} + L_e\frac{dI_e}{dt} + r_eI_e = V_0 - \frac{\int I_e dt}{c_2} \tag{3.0.14}$$

$$L_2\frac{d\iota_e I_0}{d\tau t_0} + L_e\frac{d\iota_e I_0}{d\tau t_0} + r_e\iota_e I_0 = V_0 - \frac{\int \iota_e d\tau t_0}{c_2} \tag{3.0.15}$$

Dividing $\frac{t_0}{I_O}$, we have

$$\frac{d\iota_e}{d\tau} = \frac{1 - \int \iota_e d\tau - \alpha_e \iota_e}{1 + \beta_e} \tag{3.0.16}$$

Where $\beta_e = L_e/L_2$, $\alpha_e = \frac{r_e}{\sqrt{\frac{L_2}{C_2}}}$

With starting conditions: at $\tau = 0$, $\iota_e = 0$, $\int \iota_e d\tau = 0$

and

$$\frac{d\iota_e}{d\tau} = \frac{1}{1 + \beta_e} \tag{3.0.17}$$

After laser gap breaks down ,for $t > t_s$ the discharge sequence is as follows

$$(L_2 + L_e)\frac{dI_e}{dt} - L_2\frac{dI_L}{dt} + r_e I_e = V_0 + \frac{\int I_L dt}{C_2} - \frac{\int I_e dt}{C_2} \tag{3.0.18}$$

$$(1 + \beta_e)\frac{dI_e}{dt} - \frac{dI_l}{dt} = \frac{V_0}{L_2} + \frac{\int I_L dt}{C_2 L_2} - \frac{\int I_e dt}{c_2 L_2} \tag{3.0.19}$$

$$(1 + \beta_e)\frac{d\iota_e I_0}{d\tau t_0} - \frac{d\iota_L I_0}{d\tau t_0} + \frac{\alpha_e \iota_e}{L_2} = \frac{V_0}{L_2} + \frac{\int I_L d\tau t_0}{C_2 L_2} - \frac{\int I_e dt}{c_2 L_2} \tag{3.0.20}$$

$$\frac{d\iota_e}{d\tau} = \frac{\frac{V_0 t_0}{L_2 I_0} + \frac{\int \iota_L I_0 d(\tau t_0^2)}{L_2 C_2} - \frac{\int \iota_e I_0 d(\tau t_0^2)}{L_2 C_2} + \frac{d\iota_L I_0}{d\tau} - \frac{\alpha_e \iota_e}{L_2}}{1 + \beta_e} \tag{3.0.21}$$

$$\frac{d\iota_e}{d\tau} = \frac{1 - \int \iota_e d\tau + \int \iota_L d\tau - \alpha_e \iota_e + \frac{d\iota_L}{d\tau}}{1 + \beta_e} \tag{3.0.22}$$

Similarly:

$$\frac{d\iota_L}{d\tau} = \frac{\int \iota_e d\tau - (1 + \delta)\int \iota_L d\tau - \alpha_e \alpha_1 \iota_L + \frac{d\iota_e}{d\tau}}{1 + \beta_1 + \beta_g} \tag{3.0.23}$$

With starting conditions for this phase are given by:

$\tau = \tau_s$, $\int \iota_e d\tau = (\int \iota_e d\tau)_{\tau_s}$, $\iota_e = (\iota_e)_{t_s}$, $\frac{d\iota_e}{d\tau} = (\frac{d\iota_e}{d\tau})_{\tau_s}$

being given by the numerical integration of eq.(3.0.23) up $\tau = \tau_s$ and also at $\tau = \tau_s$,

$\iota_L = 0$,$\int \iota_L d\tau = 0$, and, $(\frac{d\iota_L}{d\tau})_{\tau_S} = \frac{(\int \iota_e d\tau)_{\tau_s} + (\frac{d\iota_e}{d\tau})_{\tau_s}}{1+\beta_1+\beta_g}$ $\beta_1 = \frac{L_1}{L_2}$ $\delta = \frac{C_2}{C_1}$

$\alpha_1 = \frac{r_e}{r_e}$

Other important quantities obtained from the normalization process are

I: Laser gap voltage , for

$$\tau < \tau_s : V_g = \frac{d\iota_e}{d\tau} + \int \iota_e d\tau \tag{3.0.24}$$

II: Laser gap voltage , for

$$\tau > \tau_s : V_g = \frac{d\iota_e}{d\tau} + \int \iota_e d\tau - (1+\delta)\int \iota_L d\tau + (1+\beta_1+2\gamma\beta_{g)}\frac{d\iota_L}{d\tau} \tag{3.0.25}$$

$\gamma = \frac{L_{g1}}{Lg} = \frac{L_{g2}}{Lg}$ It is worthwhile to note that the measured voltage V_M across the laser gap is usually taken between the points V_{M1} and V_{M2} and is given by

$$V_M = V_{M1} - V_{M2} = \int \iota_e d\tau - \int \iota_L d\tau + \frac{d\iota_e}{d\tau} - \frac{d\iota_L}{d\tau} - \delta \int \iota_L d\tau - \beta_1 \frac{d\iota_L}{d\tau} \tag{3.0.26}$$

It should be noted that before laser gap switching this voltage is equal to V_g the spark-gap voltage.

I. **power absorbed by lase gap**

The power absorbed by $I_L^2 r_g$ may be normalized to average power of discharge of the $C_1 - L_1 - L_g - L_2 - C_2$ circuit. The average discharge power may be written as

$$\frac{1/2 C_1 V_0^2}{\sqrt{(L_1+L_2+L_g)(\frac{c_1+c_2}{c_1 c_2})}}$$

II. **Effective parameters controlling the discharge modes**

The performance of the laser depends on the discharge mode of

(a) $C_2 - L_1 - L_e - r_e$

circuit(external circuit) and

(b) $C_1 - L_1 - L_g - r_g - L_2 - C_2$ circuit. (The laser gap circuit) The mode mentioned here refers to the degree of damping in the respective circuit Ideally from the electrical parameters one would like to have the external circuit of current to be nearly undamped in order to have the biggest voltage reversal thus enhancing the maximum value of V_g.

On the other hand for the laser gap circuit of the biggest power developed in the gap is for the case of critical damping.

The effective parameters controlling the damping of this two circuits are :

1. For the external circuit

$$\alpha_{effe-e} = \alpha_e \sqrt{\frac{L_2}{L_2 + L_e}} = \alpha_e \sqrt{\frac{1}{1 + \beta_e}} \tag{3.0.27}$$

2. For the laser gap circuit

$$\alpha_{eff-L} = \frac{\frac{r_L}{L_1 + L_2 + L_g}}{\frac{C_1 C_2}{C_1 + C_2}} = \alpha_e \alpha_1 \sqrt{\frac{1}{(1 + \beta_1 + \beta_g)(1 + \delta)}} \tag{3.0.28}$$

Chapter 4

Result and Discussion

To study the electrical behavior of the circuit as a function of α_{eff-e} and α_{eff-L} we choose typically the following values of circuit elements which are commonly used in practical nitrogen laser which are designated and available in literature [1], [2].

L_2=0.18nH,

L_1=0.4nH,

L_{g1}=0.75nH,

L_{g2}=0.75nH,

L_g=0.3nH,

L_e=14.4nH,

C_1=20nF,

C_2=10nF,

And their ratio become

β_1=2.2,

β_e=80,

δ=0.5,

β_g=10,

γ=0.42

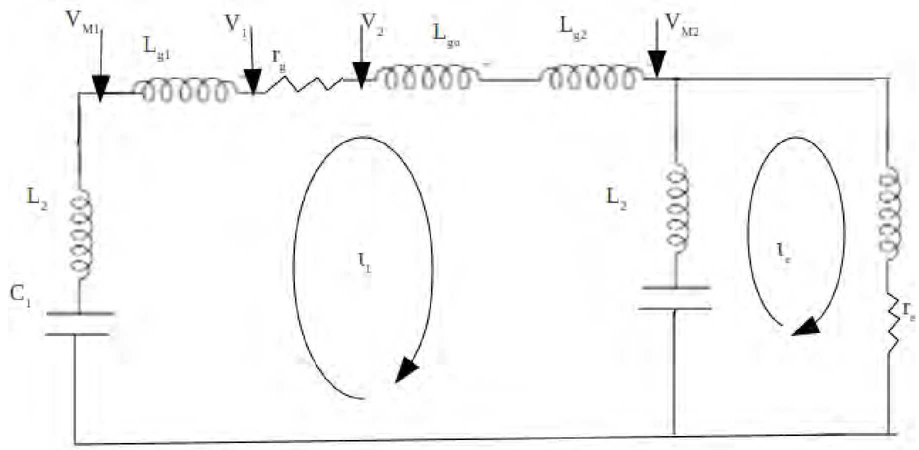

Figure 4.1: Equivalent circuit of a nitrogen laser

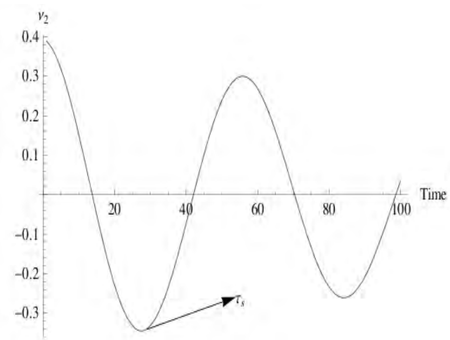

Figure 4.2: Voltage V_2

I first choose typical value for α_e=0.8 where the external circuit is lightly damped

Case:1 Laser gap critically damped: $\alpha_{eff-L} = 2$

Choosing the case of critically damped laser gap circuit for good power transfer we note that for $\alpha_{eff-L} = 2$. From the above eq.(3.0.28) This gives the value of $\alpha_1 = 11.1213$ at α_e =0.8.

Results for this case are shown fig 4.2 The voltage V_2 follows from 0.4 to 0 at $\tau = 13.5$ to -4.2 at $\tau = 27.31$.

When the laser gap is set to break down the voltage rises as the laser electrodes are

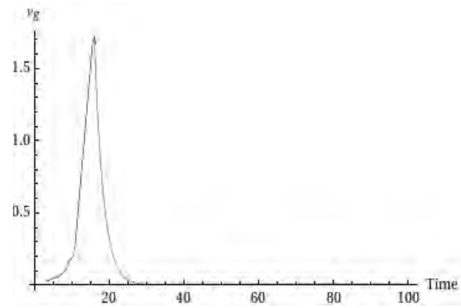

Figure 4.3: Laser gap voltage for critical case

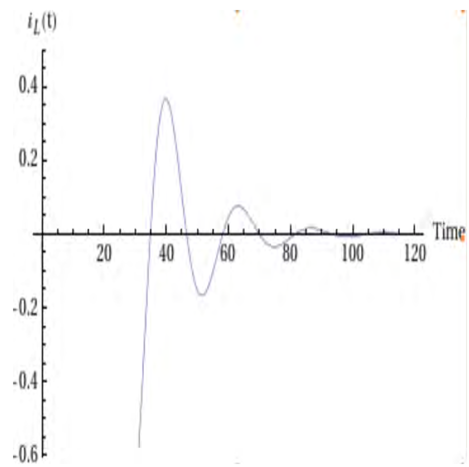

Figure 4.4: Laser gap current for more typical case of effective damping factor $\alpha_{eff-L} = 0.4$

momentarily separated only by the voltage $L_{g0}\frac{d\iota_L}{d\tau}$, however, as ι_L rises quickly, the voltage drops across the electrode quickly dominated by the term $r_g\iota_L$ so that V_2 drops once a gain to a bout V_2.

Case 2:Laser gap with effective damping factor of $\alpha_{eff-L} = 0.4$.

For this value of $\alpha_{eff-L} = 0.4$ we have $\alpha_1 = 2.22486$.

Results for this case are computed and shown in fig 4.2 V_2 drops from 0.3 to -0.34 at τ_s=27.31

then rises and oscillates.

Although the critically damped case may be the mode for maximum power, there are absorption, yet indications that the typical case reported in the literature has damping factor that is close to $\alpha_{eff-L} = 0.4$. For this value of $\alpha_{eff-L} = 0.4$ we have

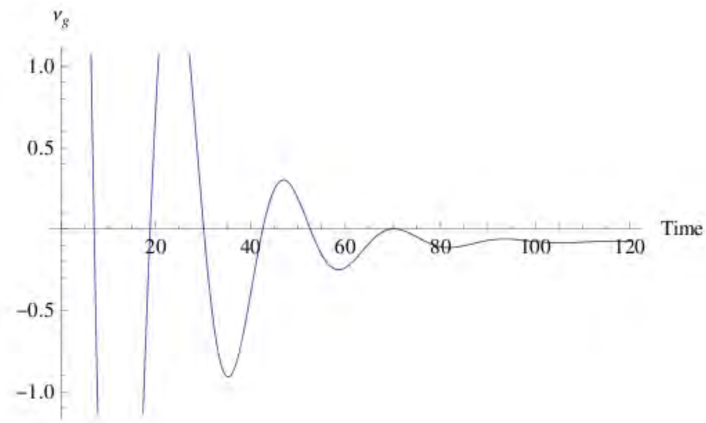

Figure 4.5: Laser gap voltage for more typical case of effective damping factor $\alpha_{eff-L} = 0.4$

$\alpha_1 = 2.225$.

Results for this case are computed and shown fig 4.2 V_2 drops from 0.3 to -0.34 then rises on laser gap breakdown and continues with an oscillation of periodic time of $18t_0$ superimposed on the slower periodic time of $43.3t_0$ of the external circuit, This behavior is although reflected in the ι_e curve

The laser gap current ι_L rises to a peak value of 0.37 in a time of $30t_0$ and oscillates in a damped mode with a periodic time of $18t_0$ the corresponding power developed across the laser gap resistance has a FWHM value of $5t_0$.

From the above results the value of $\frac{dV_g}{dt}$ for a typical nitrogen laser may be estimated. We know that a typical value of $t_0 = \sqrt{L_2C_2}$ is 1.3ns operating at a voltage of 15KV. The average $\frac{dV_g}{dt}$ is $\frac{(1.2\times15)}{(27.31\times1.3)} \sim 0.5t_0$kv/ns Such a value is experimentally known to be able to initiate the uniformity of discharge which is the first requirement in the nitrogen laser mechanism. The FWHM value for the power peak is $5t_0$ for the critically damped case and $2.123t_0$ for the more typical case of effective damping factor 0.4.

Chapter 5

Conclusion

A model for the nitrogen laser circuit is developed and scalling parameters are identified. It is shown that the external circuit should be little damped so as to maximize the rate of laser gap in order to ensure uniformity in breakdown across the laser gap. The laser gap voltage circuit should be critically damped from the point of view of optimum laser gap power absorption.

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Declaration

This Project is my original work, has not been presented for a degree in any other University and that all the sources of material used for the project have been dully acknowledged.

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This Project has been submitted for examination with my approval as University advisor.

Name: **Prof. A.V. Gholap**

Signature:– – – – – – – – – ––

Place and time of submission:

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