Assignment
On
LASER THEORY
Course No: EEE 6503

Topic: UV Gas Lasers (CHAPTER 10)

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Introduction:

The most important ultraviolet lasers are the nitrogen and the excimer lasers. These lasers employ a similar technology. Both lasers are molecular lasers in which the lasing species is a diatomic molecule. In the case of the nitrogen laser, the active lasing species is nitrogen molecule; in an excimer laser, the active lasing species is a transient molecule consisting of a halogen and an inert gas (such as argon or krypton). Though the structure of both lasers is physically similar, excimer lasers are much larger and produce more power outputs than nitrogen lasers.

Development of Nitrogen Lasers:

Nitrogen laser was developed in 1963 by H.G. Heard. He succeeded in producing 10 W pulses of UV light. Within four years a radical shift in the design methodology had been developed, yielding peak powers in the MW range. Development continued and TEA (Transverse Electrical discharge at Atmospheric pressure) nitrogen lasers capable of producing MW powers using N_2 at atmospheric pressures appeared. This laser was an important milestone in UV laser development that led directly to the more powerful excimer laser. Today, the nitrogen laser is still a useful source of coherent UV light, producing pulses with millijoule energies and pulse widths around 10 to 20 ns.

Lasing Medium of Nitrogen Lasers:

Excitation of the nitrogen molecule is accomplished by collision of high-energy electrons in a gas discharge. The energy levels of the nitrogen molecule as they apply to this laser are outlined in Figure 1.

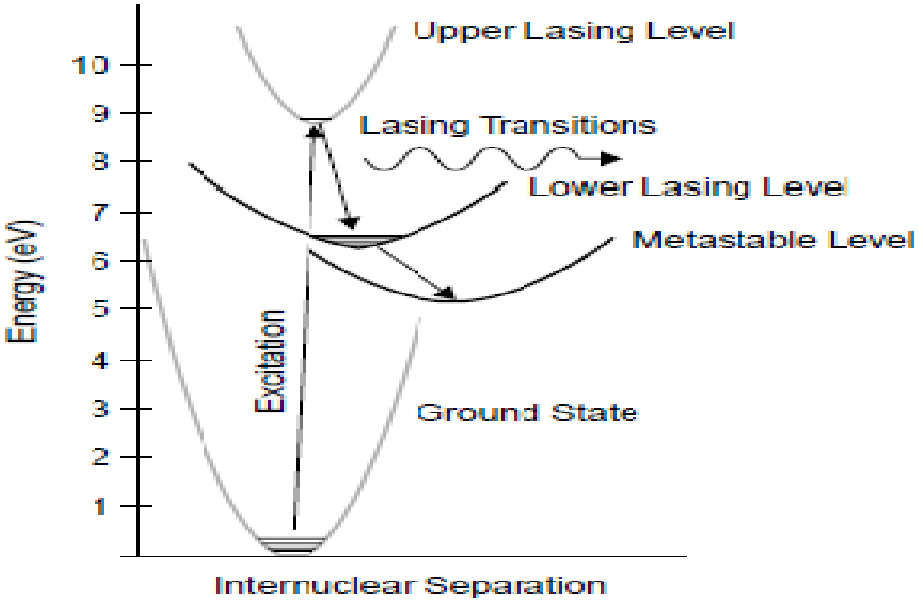

Fig 1: Molecular N_2 laser energy levels.

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 electron to enter the ULL (Upper Lasing Level), termed C^3 II energy band of the molecule. From the ULL the molecule falls to LLL (Lower Lasing Level), termed B^3 II energy band, emitting a photon of UV light in the process. Transitions in a normal nitrogen laser operating at 337.1 nm are in the 0-0 band, in which the only levels involved are those with the lowest vibrational state (v=0). Other transitions are possible in the 0-1 band, where the ULL is the same lowest state (v=0), but LLL involved is the v=1 vibrational state. The transition is a smaller jump than the 337.1 nm and hence has lower energy with a wavelength of 357.7 nm.

After emitting a photon in the lasing transition, the molecule than falls to a metastable state and finally, to the ground state. In this respect the system resembles copper-vapor laser with the inclusion of a metastable state. In all, molecular nitrogen lases at 61 known wavelengths in the 0-0 band between 336.4903 and 337.9898 nm, with the vast majority lines clustered around 337.1 nm, with spacing between lines typically below 0.005 nm and a FWHM is about 0.1 nm. Nitrogen lasers can also operate on transitions involving the ionized molecule (N_2^+) with an output at 427 nm.

For Nitrogen lasers the ULL has a lifetime that is pressure dependent according to

$$t = \frac{36}{1+\frac{p}{58}}$$

Where t is the ULL lifetime in nanoseconds and p is the pressure in torr. So for a nitrogen laser operating at 60 torr, the ULL lifetime is about 18 ns. On the other hand, the LLL lifetime is about 10 microseconds. Since the ULL lifetime is less than LLL lifetime, CW laser action is impossible, but pulsed laser action is possible provided that the laser mechanism can pump energy preferentially and quickly into the upper lasing level to generate a population inversion. In a nitrogen laser this is done by a massive electrical pulse where electron collisions cause the preferential population of the upper energy band first. After about 20 ns, this energy will decay to the lower level, population inversion is lost, and lasing action will quickly cease. Besides, nitrogen molecules at the lower state absorb UV light strongly, so gas in the laser channel quickly absorbs laser energy. On average, the pulse length the pulse length of the nitrogen laser is less 20 ns. The value of 20 ns is for a low pressure laser design where lasing gas is at a pressure between 25 and 60 torr, but in a TEA laser the pressure is much higher,760 torr or more,so pulse length is about 2 ns.

Gain and Optics of Nitrogen Laser:

Gain for a nitrogen laser is on the order of 40 to 50 dB/m or more, depending on the specific laser. The highest gain reported for a nitrogen laser was 75 dB/m. So the gain of nitrogen laser is very high because at the lower gain figure of 40 dB/m, light is amplified by a factor of 10,000 for every meter of travel through the laser tube.

A single high gain reflector is frequently installed in a nitrogen laser tube as well as a 4% reflective output coupler. This triples the output power. This also decreases beam divergence by at least 50%. The coating of the high reflector must reflect UV(aluminum is frequently used), and windows on the laser tube must be made of quartz or some other material that is transparent to UV radiation.

Nitrogen Laser Structure:

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 overvoltage 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, where two capacitors are essentially in parallel separated by the laser channel. Both capacitors charge simultaneously through the charging inductor until the spark gap fires when the breakdown voltage is reached (typically, about 15 kV for a small laser). When the spark gap conducts it drains charge from capacitor C1, making the top terminal of C1 negative. A massive voltage difference appears across the laser gap since the left side of the tube is now negative and the right side is positive. Charge from C2 flows across the laser channel as a pulse of very high electrical current, in many cases thousands of amperes.

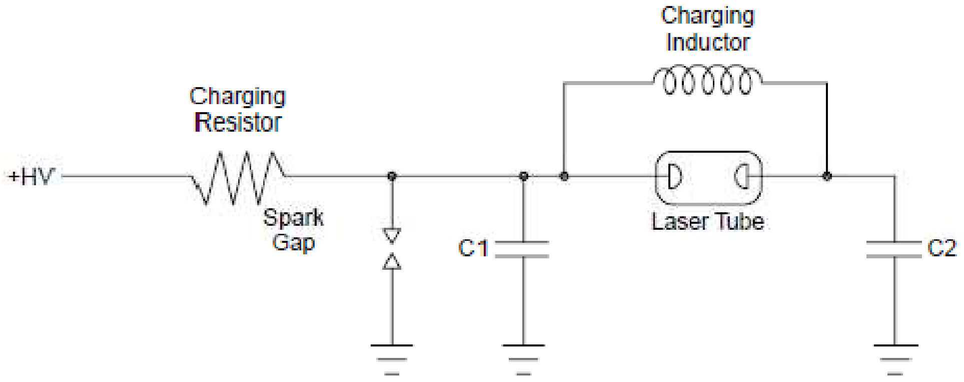

Figure 2 : Electrical schematic of a Blumlein laser.

The sequence of events during firing of the nitrogen laser is outlined in figure 3. In this design, common for small laboratory-type nitrogen laser the capacitors are fabricated on an epoxy-glass substrate. Two capacitors are formed with copper foil on the top of the board and the bottom of the board is the common terminal for both. The spark gap 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(figure 3a). As the capacitors are charged, the voltage across the capacitors as well as the spark gap rises until breakdown occurs (figure 3b) and the spark gap conducts. No voltage appears across the laser channel

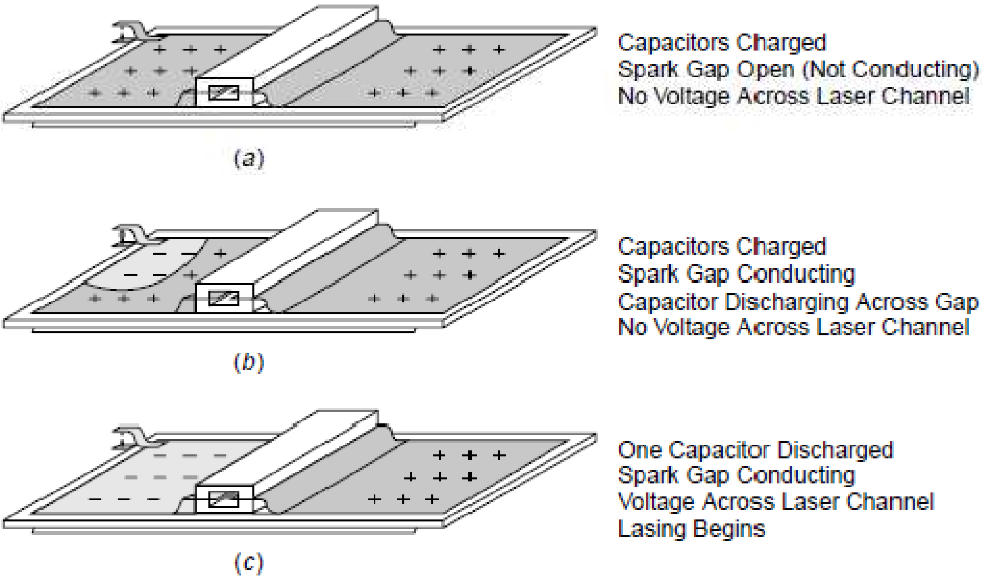

Figure 3: Nitrogen laser discharge sequence.

until the charge at rear of the left capacitor has been drained and a voltage differential appears at the rear of the laser channel. The discharge in the laser thus begins here. Light emission follows the discharge and a beam emerges from the laser.

A practical nitrogen laser based on this design is pictured in Figure 4.The initiating spark gap is visible in the upper-left corner. It emits an intense flash of light since high current pass through it. The charging inductor bridges the laser tube. This 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 corner of this laser.

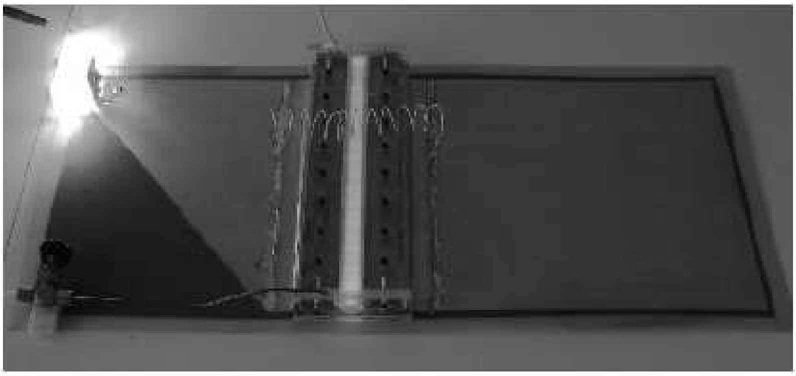

Figure 4: A practical nitrogen laser

As well as operating at low pressures (generally 20 to 60 torr), nitrogen lasers may operate at atmospheric pressure in a TEA configuration. These lasers are physically similar to the low-pressure types and most use a Blumlein configuration. In the case of a TEA nitrogen laser the lifetime of the ULL decreases to about 2.5 ns. The requirements for a fast discharge are more pronounced in a TEA laser, which must be constructed to keep inductances in the discharge path to an absolute minimum and dielectrics for capacitors are kept very thin (since the intrinsic inductance of a transmission-line capacitor is proportional to the thickness of the dielectric). The laser channel is mounted directly on top of the capacitors. A practical TEA laser is pictured in figure 5, in which the spark gap is located in the upper-right corner of the figure and the long transverse electrodes are visible down the center of the laser. Unlike the low-pressure laser, which features a consistent and even discharge between the electrodes, discharge 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.

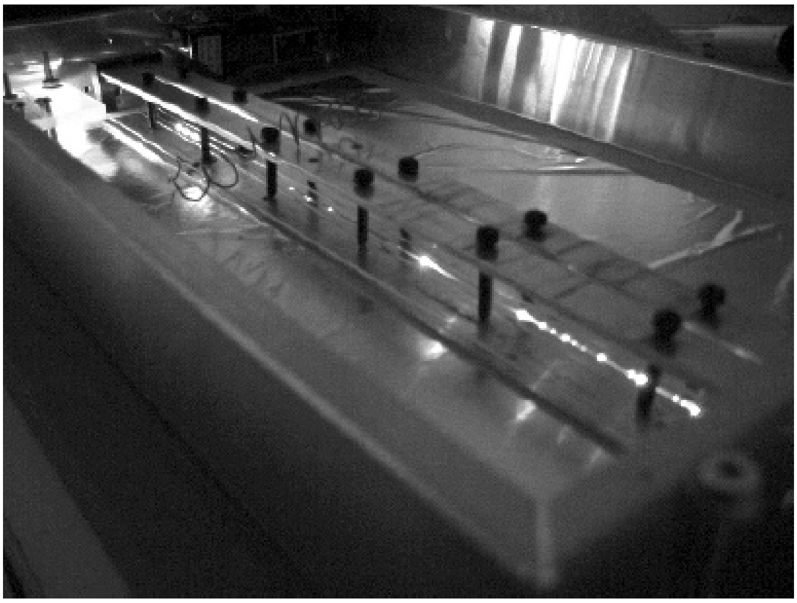

Figure 5: A practical TEA nitrogen laser.

Most small commercially available nitrogen lasers use spark gaps for their simplicity. These spark gaps are filled with nitrogen gas for reliable, predictable firing. Filling with nitrogen also eliminates the objectionable production of ozone when the gap fires. In some large 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, an important feature when laser is used in a laboratory experiment requiring synchronization and precise timing.

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 discharge as well as cool the laser. 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). Another alternative is the use of a carbon dioxide gas mixture consisting of helium, nitrogen, and carbon dioxide. With suitable optics this laser operates as a TEA laser, producing fast, short pulses of light at 10.6 µm in the infrared.

Output Characteristics of Nitrogen laser:

Beam quality is poor in a nitrogen laser, but the gain is high and the output consists of highly amplified spontaneous emission. In a nitrogen laser, photons often make only one pass through the amplifier before exciting. 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 large. Molecular nitrogen lases at 61 known wavelengths between 336.4903 and 337.9898 nm, but the vast majority of lines are clustered around 337.1 nm, so the FWHM of the combined output from these lines is about 0.1 nm.

Applications of Nitrogen laser:

a) Nitrogen lasers are excellent pump sources for pumping dye lasers.
b) Nitrogen lasers are useful for exciting fluorescence in substances other than laser dyes, allowing studies of these molecules.
c) Nitrogen lasers may also be used for small microcutting procedures on individual biological cells or for trimming thin films for semiconductor industry.
d) With a typical pulse energy of less than 1 mJ and a repetition rate under 100 Hz, Nitrogen lasers yield a low-cost source of intense UV light.

Introduction to Excimer Laser:

Excimer lasers produce intense pulsed output in the ultraviolet.

In the excimer laser the lasing molecule consists of a halogen and an inert gas. The molecule is transient and exits for only a moment in time. Like the nitrogen laser, a fast, high-current discharge is required to produce the excimer molecule, but excimer lasers are considerably more complex since they operate at high pressure and one of the active gases is highly toxic and corrosive. Modern excimer lasers produce pulses with energy ranging from 0.1 to 1 J and can (for a large industrial laser) produce these pulses at a rate of over 300 per second. Pulses are fast, with a FWHM of 10 to 30 ns. Fast pulses combined with high peak powers serve to ablate target material, a desirable effect for many processing purposes.

Lasing Medium of Excimer Laser:

Energy levels in an excimer laser are defined by the state of the atomic components. When unbound, the energy of the system depends purely on the separation between the individual atoms; as the atoms move closer together, energy rises. This is illustrated by the lower curve in Figure 6. The lower energy level in an excimer system is defined as a separation of the halogen and inert gas atoms. The upper energy state is formed when the inert atom and the halogen form an excited dimer (excimer) molecule. The energy of the excimer molecule is much higher than that of the unbound individual atoms and also depends on the interatomic spacing. There are numerous vibrational levels. Collectively, These closely spaced levels form a band serving as the upper lasing level.

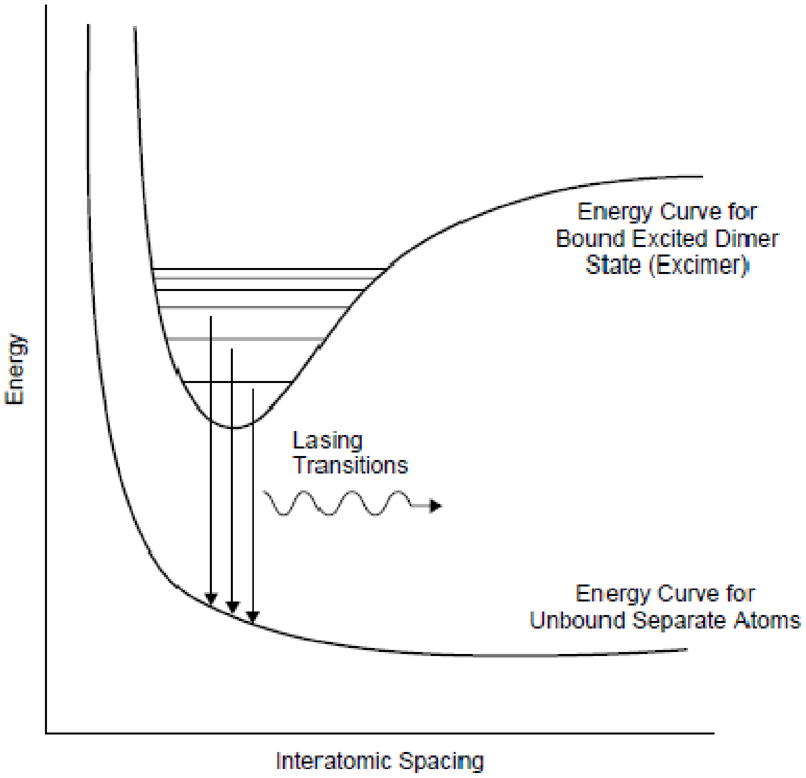

Figure 6: Excimer laser energy levels.

Various excimer species are outlined in Table 1, which also lists the relative power output relative to KrF, the most powerful excimer laser. Although KrF produces the most powerful output, other gas mixtures, such as XeCl, are popular for use in excimer lasers. Shortcomings of KrF laser include the output wavelength is absorbed readily by air, and the extremely corrosive nature of fluorine, which shortens the useful life of the gas mixture in the laser. The problem of ArF laser is that it produces a wavelength so short that it produces ozone gas from atmospheric oxygen as it passes through air. When using ArF, beam paths must be enclosed and flushed with dry nitrogen, helium, or argon. XeCl, on the other hand, has a longer wavelength, allowing better transmission in air and the use of considerably cheaper optics. The gas mixture also has a much longer useful lifetime. The useful lifetime of lasing gases may also be extended by using a cryogenic gas processor in which the lasing gas mixture is passed through coils immersed in liquid nitrogen to trap impurities in the gas mixture. A cryogenic gas processor is shown in Figure 7. In the figure two copper lines, evident on the top of the processor, connect to the laser vessel, and laser gas is recirculated continually by a pump in the processor through these lines and the processor's cold trap.

Table 1: Excimer Species

Laser Species	Wavelength (nm)	Relative Power Output
ArF	193	0.5
KrF	249	1.0
XeCl	308	0.7
XeF	350	0.6

Figure 7: Cryogenic gas processor.

Gain and Optics of Excimer Laser:

Like nitrogen lasers, the gain of excimer lasers is extremely high. A single rear mirror and an output coupler are employed in the excimer lasers. Divergence of the beam is reduced when a full optical cavity is used, and alignment is easy since the laser operates even when cavity mirrors are completely misaligned. The beam is rectangular in profile. A stable resonator consisting of a totally reflecting rear mirror and an output window yields the highest output pulse energies and uniform energy distribution throughout the beam, although divergence is somewhat high. Unstable resonators are often used with excimer lasers to improve the high divergence. This type of arrangement also increases the brightness at the center of the beam, making the beam more focusable for cutting applications. Unlike nitrogen lasers, quartz cannot be used for most excimers since fluorine attacks the material. Output couplers are hence made primarily of magnesium fluoride.

Excimer Laser Structure:

Like TEA lasers, excimer lasers have two long, transverse electrodes and the gas pressures are at atmospheric or greater. But the lifetime of ULL of excimer laser is greater than that of TEA nitrogen laser, so the requirements for a low-inductance and hence fast electrical discharge path are somewhat relaxed. Most excimer lasers use a discharge circuit consisting of a single large capacitor and a low-inductance thyratron switch, as outlined in Figure 8.

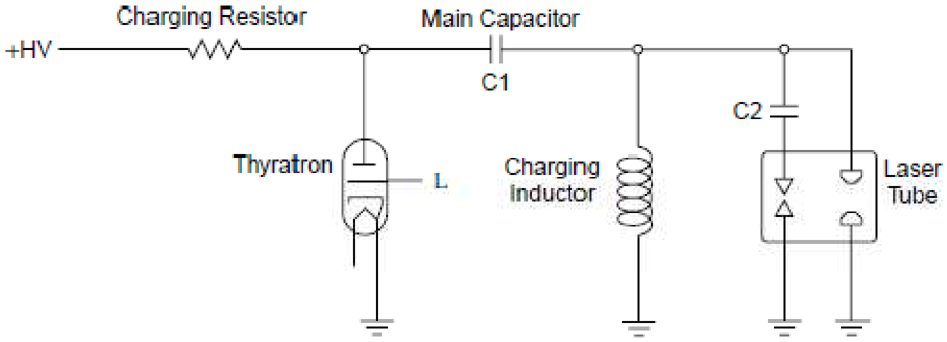

Figure 8: Excimer laser discharge circuitry.

The main capacitor (C1) charges with high voltage of about 40 kV through the charging resistor and the charging inductor. To fire the laser, the thyratron is triggered, shorting the left side of C1 to ground. Current then flows from capacitor C1 through the laser tube, where the discharge occurs. Essential components of the excimer laser high voltage section are annotated in Figure 9. The capacitor is the large white block and is connected to the thyratron via a thick copper tube.

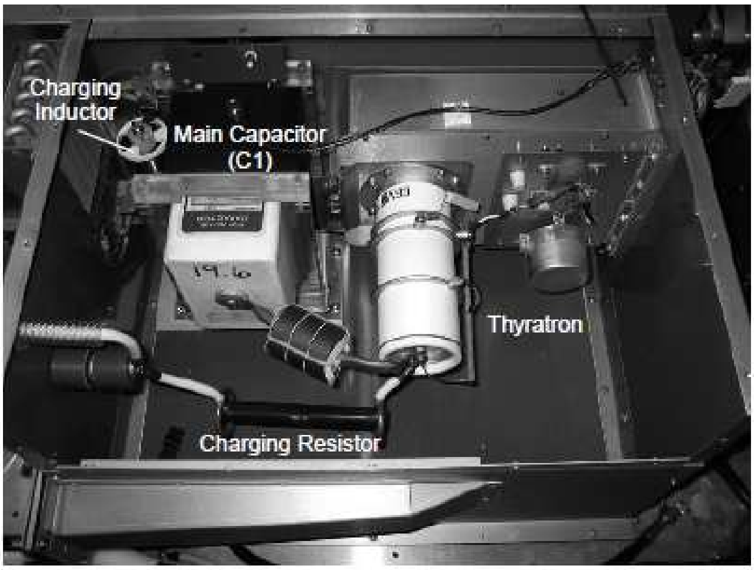

Figure 9: Excimer laser high-voltage section.

Current flowing from the capacitor flows into the laser tube but the discharge does not occur immediately since the pressure of the laser tube is high and gas inside the laser channel is not yet ionized. Ionization is performed by current flowing through small capacitors C2 and jumping small preionization spark gaps inside the laser tube immediately adjacent to the main laser discharge channel. UV radiation produced from these sparks ionizes gas in the laser channel, which then conducts the main discharge current, producing a laser pulse.

Since the input energy to the laser tube is several kilowatts, there is a large amount heat that must be extracted from the lasing gas. This is accomplished by using a large squirrel-case blower and water-cooled heat exchanger. Laser gases are forced around the vessel at high speeds: through water-cooled coils where the gas is cooled and recirculated through the laser. The heat-removal mechanism is diagrammed schematically in Figure 10 and shown in Figure 11, where the laser channel and capacitors have been removed to reveal the blower and heat-exchanging tubes.

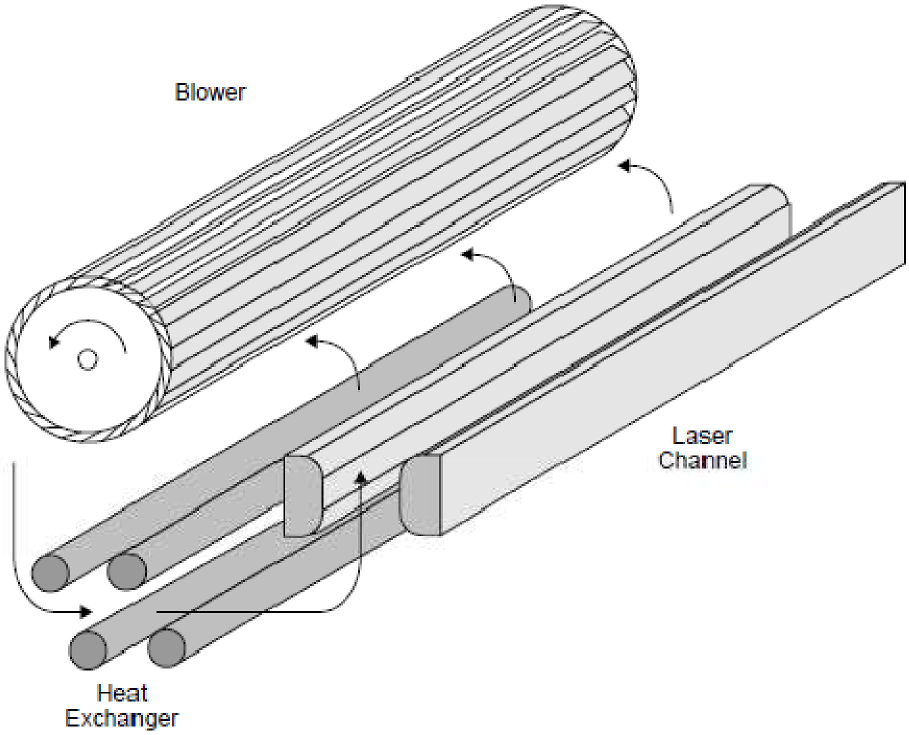

Figure 10: Excimer laser heat removal mechanism and gas flow.

Figure 11: Excimer laser heat exchanger and fan.

Applications of Excimer laser:

a) Used in lasik surgery.
b) Used as a UV source in photolithography.
c) Used for glass marking applications .
d) ArF(and sometimes KrF) excimer is used to manufacture fiber Bragg grating for optical fiber communications.
e) Used in cutting and material processing applications, drilling inkjet printer nozzle holes, and marking wires.

THE END.