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EXPERIMENTAL MEASUREMENT OF ANGLE OF DIVERGENCE

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Abstract :-

Our intention in building the nitrogen laser is to investigate the angle of divergence in details. We try to give logical interpretation of the behaviour of the laser output power and angle of divergence that has not yet been given by anybody else. An extensive effort to explore the variation of angle of divergence under different experimental conditions has been carried out.

1.Introduction :- Many reaserchers have already discussed about the applications of cyclic lasers such as nitrogen laser, copper vapour laser and stated that the cyclic lasers have wide applications in the fields of science and technology. Since the nitrogen laser is a good candidate from the class of cyclic lasers and fabrication of the nitrogen laser is easy and cheaper, many workers in the field can built it and investigate the physics and applications of the class of cyclic lasers. Moreover, several aspects of nitrogen laser (cyclic laser) are still to be stuided in details in order to improve upon the laser output characterstics. Our intention in building the nitrogen laser is to investigate the angle of divergence in details.

2.Desigin And Building Of Nitrogen Laser System

We design and build 3371 Å pulsed nitrogen laser having low repeatition rate. A Blumlein line pulse forming network acts as the pump for the excitation of the laser medium. One meter by one meter glass epoxy having 3 mm thickness double copper clad acts as a parallel plate condenser in the circuit. The copper clad is properly removed and the sheet is converted into two condensers connected parallel to each other with a gap provided in the middle of the sheet for joining the laser cavity. A metal spark gap joined in a corner of the parallel plate condenser plays a role of the switch in the circuit. Two square brass rods of one meter length and 2.5×2.5 cm^2 cross-sections are held parallel to each other by the plates of plastic glass running parallel to the length of the brass rods. The brass rods and plastic rods together with quartz windows at the two ends form the discharge tube. One of the brass rods is shaped into 3 mm thick rounded anode. A stack of three hacksaw blades packed into a groove made in another brass rod plays the role of the cathode. The brass rods are adjusted in such a way that the gap of 1 cm is left in between two electrodes throughout the length of the bross rods. Copper strips joined along the length of the brass rods are connected to the copper clad. A hollow studs connected to the plastic glass at the two ends of the discharge tube act as the gas inlet and outlet for the supply and removal of the nitrogen gas and for the maintanace of the gas pressure in the discharge tube. A pressure meter joined in the middle of the discharge tube helps in measuring the gas pressure in the tube. The schematic diagram of the Blumlein line with joined discharge tube and cross-section of the laser cavity is shown in fig 1

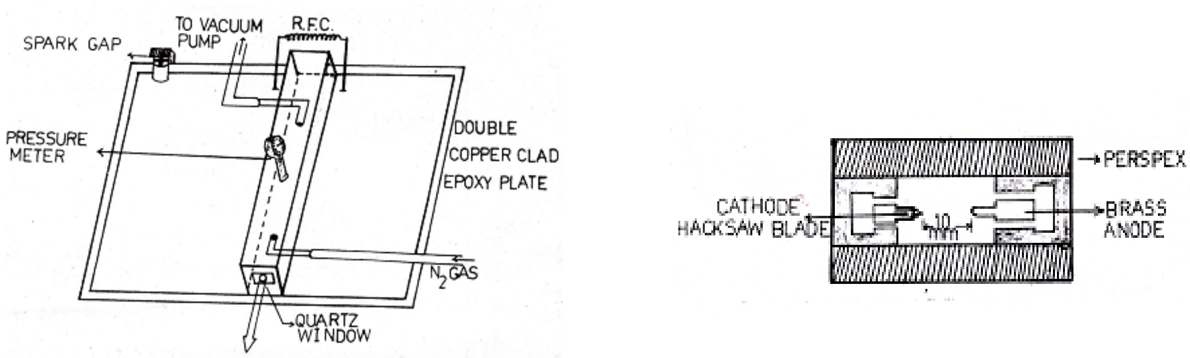
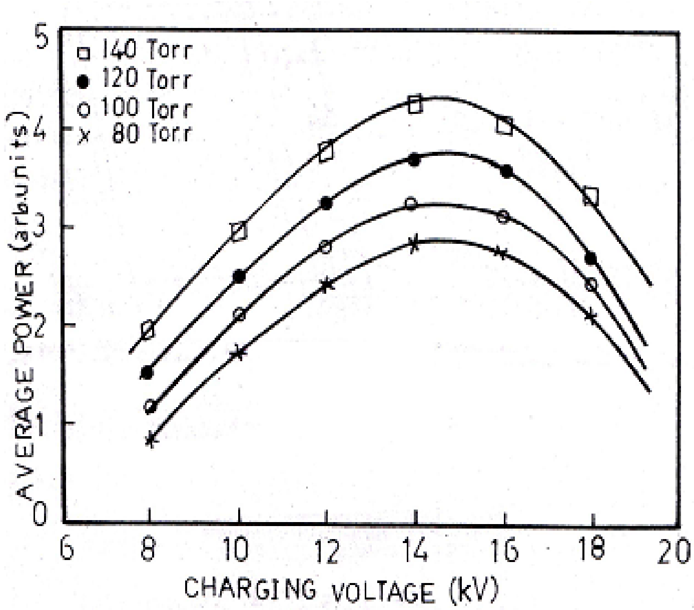


Fig 1 Schematic diagdram of N_2 laser pumped by Blumlein line and cross section of the discharge tube

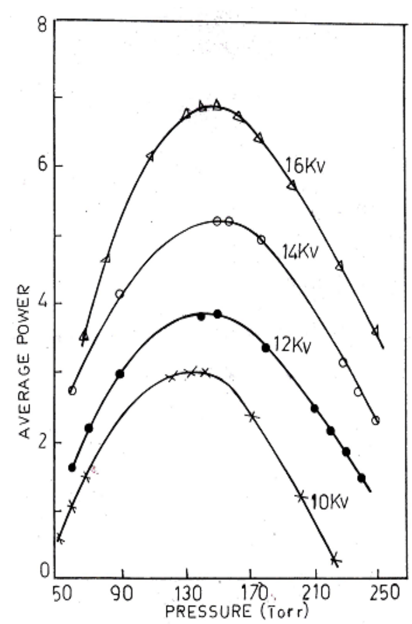
When the spark gap is fired one of the condensers in the Blumlien line gets discharged and another condenser retains high voltage. The firing of the spark gap produces potential difference between the electrodes in the discharge tube. When the potential difference reaches a typical value the gas breaks down and glow discharge is produced and we get the laser beam from both the ends of the discharge tube even without using any reflecting mirror. We study the performance of the laser as a function of the gas pressure and charging voltage.

3 Measurement Of The Laser Output Power

We measure the laser output power as a function of a charging voltage for different fixed values of the gas pressures and the results are displayed in the figure 2. We also measure the laser output power as a function of the gas pressure for different fixed values of the charging voltages and the results are displayed in the figure 3.



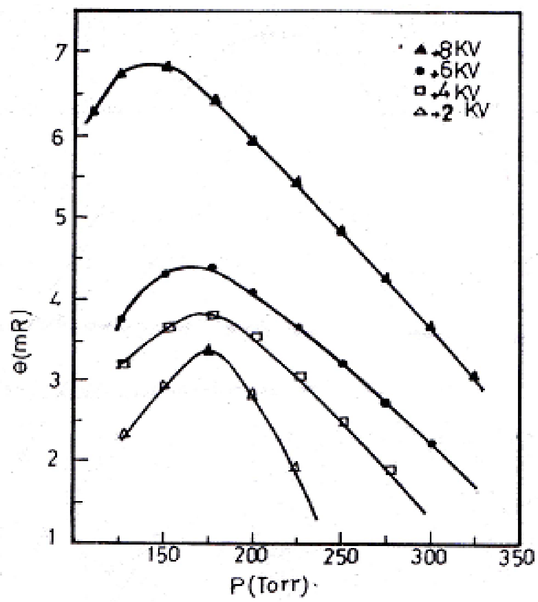
Laser power as a function of charging voltage for different values of gas pressure Fig-2



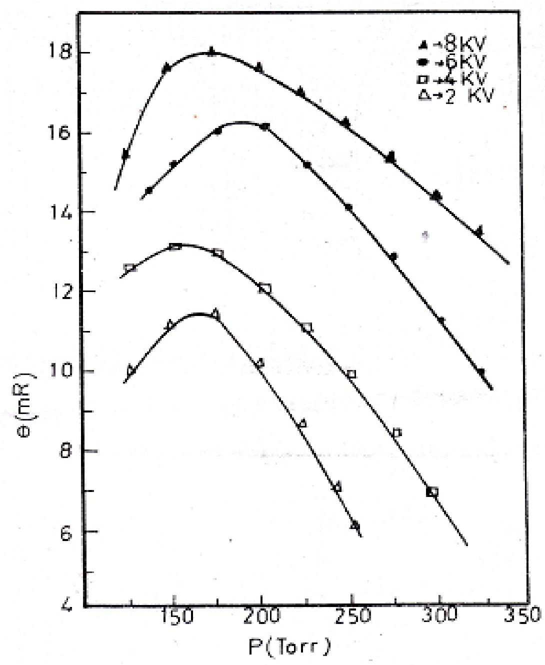
Laser power as a function of gas pressure for different values of charging voltages Fig-3

4. Measurement Of Angle Of Divergence

For the measurement of angle of divergence we keep a flurosent screen in vertical plane at a distance of 1m from the exit end of the discharge tube. The vertical and horizontal dimensions of the output laser beam were measured and from these measurements the angle of divergence is obtained. We measure the vertical and horizontal angles of divergence as a function of the gas pressure at the charging voltages 2 kV, 4 kV, 6kV and 8 kV and the results are displayed in the figure 4 and 5 respectively. The angle of divergence shows that large variations when parameters like gas pressure, charging voltage are changed.



Angle of divergence (in vertical direction) as a function og gas pressure Fig-4



Angle of divergence (in horizontal direction) as a function og gas pressure Fig-5

5.Results And Discussions

At a fixed value of the gas pressure the laser output power increases initially with the increase in the charging voltage as shown in the fig 2. The laser power reaches a peak value at a certain value of charging voltage. If the charging voltage is further increased the laser power is decreased. When the gas pressure is fixed the breakdown voltage of the gas in the discharge tube might remain almost same for all the values of the charging voltages. The discharge current might change as the charging voltage is varied and consequently evoluation of the discharge electron temperature varies. Once the gas is broken down the capacitor gets discharged through the gas with the rate characterised by the time constant C Rd (where Rd is the impendance of the gas). The impendance of the gas is determined by the electron density and electron temperature (1). The electron density as well as electron temperature change rapidly (2,3) during the evolution of the discharge pulse consequantly changing the value of gas impendance Rd. The time constant C Rd does not remain constant and the investigation of the process of formation of the the discharge pulse becomes complicated. But one might try to find the qualitative relation between the output power and the charging voltage. In fact as the charging voltage increases the energy stored (CV) by the condenser increases linearly with voltage. A part of the energy stored is converted into laser energy. Therefore to first sight it seems that the laser energy should go on increasing as the charging voltage is increased. However this does not take place because at all electron temperatures same fraction of the input energy is not converted into laser energy. At a fixed value of the gas pressure the break down voltage gets fixed and the increase in the charging voltage increases the discharge current and, in term, the electron temperature.

The laser output energy is determined by the number of molecules excited to the laser state, which in term is governed by the electron temperature, density of the nitrogen molecules in the ground state and the electron density (equations I to III).

$$\frac{dN_2}{dt} = N_o N_e R_{o2} + N_1 N_e R_{12} - (D_{20} N_e + D_{21} N_e + T_2^{-1}) N_2 -$$
$$\frac{N_2}{T_2} - \sum_m A_{mn} N_m + N_2^2 X_2 - S_{21}\left(N_2 - \left(\frac{g_2}{g_1}\right) N_1 \right) + OTH \qquad \text{I}$$

$$\frac{dN_1}{dt} = N_o N_e R_{o1} - (N_e D_{10} + T_1^{-1}) N_1 + \sum_n A_{nl} N_n + N_1^2 X_2 +$$
$$S_{21}\left(N_2 - \left(\frac{g_2}{g_1}\right) N_1 \right) + N_e D_{21} N_n + OTH \qquad \text{II}$$

$$\frac{dN_0}{dt} = -(R_{20} + R_{10}) N_e N_0 + (T_{10}^{-1} + D_{10} N_e) N_1 + (T_{20}^{-1} + D_{20} N_e) N_2 \qquad \text{III}$$

Where N_0, N_2, N_1, N_e are the densities of the ground state , upper laser state lower laser state and discharge elrctrons respectively .

R_{02} and R_{01} are the electron impact excitation rate coefficient of upper and lower laser state from the ground state of the molecule.

D_{20} and D_{21} are the electron impact deexcitation rate coefficient of the upper and lower states.

g_2 and g_1 are statistical weights of the states.

T_2 and T_1 are fuloresesence life time of the laser states.

A is the *Einstein* A coefficient

S_{21} is stimulated emission rate coefficient including the radiation at the laser wavelength.

The electron density goes on increasing at higher electron temperatures. The behavior of EIE rate coefficients and population inversion density also shows that the number density of the laser states should go on increasing as the electron temperature is increased. The only way to explain the decrease in laser energy at higher charging voltage is the decrease in the ground state density of the molecules. The ground state density might decrease by one of the two process

i) excitation of the molecules to higher energy states and

ii) ionisation (or disociation) of the nitrogen molecules.

Therefore, the experimental results clearly indicate that it must be the process of ionisation (or disociation) which reduces the ground state density. At high electron temperature large fraction of the input energy is utilized in the process of ionisation (or disociation) of nitrogen molecules and a small fraction of the energy is utlised in the process of excitation of the molecules to the laser states. Consequently the laser output power decreases at higher charging voltage.

In the figure 3 the variation of the average laser power as a function of the pressure is dipicted. When the gas pressure is increased the laser power increases in the beginning and it reaches peak value at a certain value of the gas pressure (130-140 Torr). As the pressure is further increased the output power decreases monotonically. It seem at low pressure the breakdown voltage of the gas is low and the electron temperature in the discharge is also low. This gives rise to low output power because of the less magnitude of EIE rate coefficient at low electron temperatures. As the pressure in the discharge tube is increased breakdown voltage increases and consequently the electron temperature as well as the EIE rate coefficient increases increasing the laser output power. Further increase in the gas pressure increases the electron temperature to still higher value leading to the ionisation of the nitrogen molecules leaving behind very few molecules in the ground state.

After carrying out the extensive work and analysing the results we would like to point out specifically that the ionisation of the nitrogen molecules play vital role in the determination of the laser output power.

The figure 4 and 5 shows that when the charging voltage is fixed and the gas pressure is increased the angle of divergence increases and reaches a peak value at a certain value of pressure. Further increase in the gas pressure decreases the angle of divergence. The figures also show that the angle of divergence increases initially with increase in the charging voltage and it decreases as the voltage is further increased. It is also noticiable that vertical spreed of the laser beam is less than the horizontal spreed. The vertical angle of divergence ranges from about 1 mrad to about 7 mrad and the horizantal angle of divergence ranges from about 6 mrad to about 18 mrad.

The results of the experimental measurements of the angle of divergence is compared with the computations carried out in the present work. Furthermore the present computations can be compared with the experimentally measured values of the angle of divergence by several workers in the field. The pertinant data of measurement of angle of divergence in the experimental work is tabulated in table-1 (4-18). Furthermore, the results in the figures 3 and 4 may be compaired with the results in the variation of peak power across laser beam in horizontal and vertical directions. In both the cases it is clear that the vertical spread of the beam is less than the horizontal spread of the beam. In the experimental observation of *Godard* and *Vannier* (9) and *Sam* (10) the vertical spread of laser beam is less than horizontal spread of the output beam. The theoretical expression for the angle of divergence shows that it is determined by the corresponding dimension of the beam. If the laser output beam has rectangular cross section the spread of the beam is different along different directions. The beam spread is more along the length of the beam than that along the breadth of the beam. This is because the vertical dimension of the laser beam is less than the horizontal dimension. The calculation of the angle of divergence also indicate that the angle of divergence increases as the beam dimension increases. Thus it is evident from the experimental work and theoritical calculations that the angle of divergence may be controlled by controlling the dimension of the laser beam.

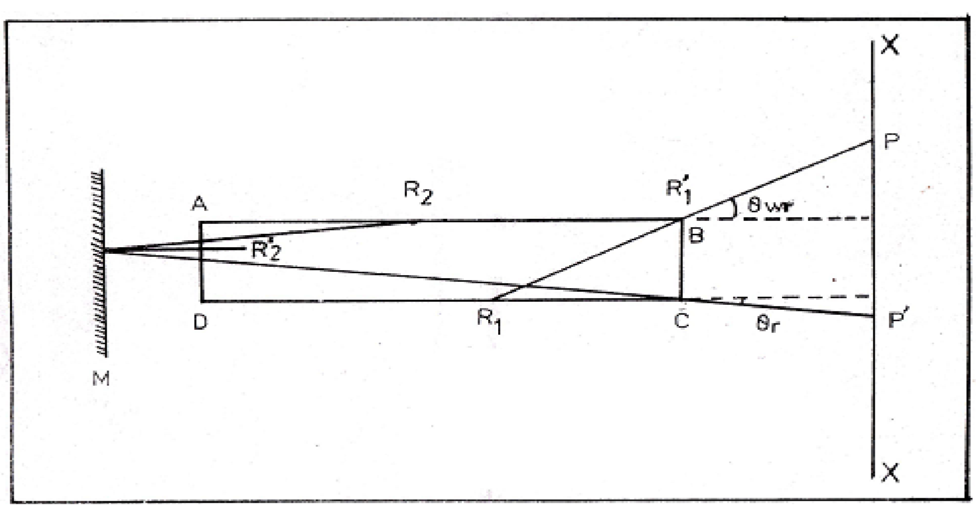
For further analysis of the measurements of the angle of divergence the corresponding results may also he compaired with the power measurements of nitrogen laser. The qualitative behaviour of the curves in the figures 2,3, 4 and 5 is identical. Therefore, we may say that. the angle of divergence increases with the increase in the laser power. In other words it may be stated that the angle of divergence increases with the increase in the inversion density because the laser output power increases in proportion with the initial inversion density. This may be compaired with the computed angle of divergence as a function of initial inversion density. The compuated angle of divergence of the laser beam increases nearly linearly with the increase in the initial inversion density.

6. **Conclusion:**

Thus we conclude that there is quite good agreement between the theoretical results and the experimental work.

The lasers with output beam of circular cross section have symmetric spread about the axis of the laser beam. The angle of divergence of the infra-red nitrogen laser and the laser operating on other wavelengths of second positive system is less because pluse width of the laser output is more. The radiation makes many round trips between the reflecting mirrors and this leads to the low angle of divergence.

The output of the laser without mirror has large angle of divergence and the use of reflecting mirror reduces the angle of divergence. This has been experimentally observed by Fischer et al (5) and it can be very well understood by considering the fig -6.



The effect of reflection on the angle of divergenceThershold laser length (Fig-6)

The ray reaching at point P is emerring as a laser ray having maximum angle of divergence θ_{wr} . It is coming out of laser cavity without under going any reflection. The ray reaching at point P' is emerging as a laser ray having maximum angle of divergence θ_r and undergoing one reflection. All other rays emerging have less angle of divergence. Thus the figure shows that the ray coming out without reflection has more angle of divergence than the ray coming out after reflection.

Table -1

Voltage kV	Pressure torr	Laser Power kW	Pulse Width nsec	Distance between electrodes mm	Angle of divergence mrad	Ref
A)	LONGITUDINALLY EXCITED					
30	---	--	--	--	3	4
18	10-17	28-140	3-6	4	Reduced from 3 to 1	5
B)	TRANSVERSELY EXCITED					
15-25	20	200	20	3.1	1	6
10-15	10-20	25-160	10	-	1	7
2-6	50	200-1500	4	2-12	0.06	8
11-17	70-90	170	5	250	6-8 hor 2 ver.	9
14-24	110	1000	5	-	0.2	10
10-30	1 atm	100-400	0.3	-	4	11
40	2250	700	1	-	15	12
1-40	3750	1000	1	1-6	3	13
30	1 atm	1000	0.6	3	1	14
15	1 atm	250	1	1.5-3.5	6×2	15
15-20	1400	30-150	-	1	5	16
30	1 atm	60	0.65	5	10	17
15	1 atm	1.3-1.5	1.2-1.8	1.5-3.5	0.1	18

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