Construction of one Megawatte Te-Blumlein Type Nitrogen Laser

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Eisei TAKUSHI,* Yasumasa KAKIHANA,** and Sigemitsu MAEKARA***†

Abstract

A high power (1 megawatt) nitrogen laser has been designed and constructed using ceramic capacitors. Active length and volume of cavity are 93 cm and 600 cm^3 respectively. The threshold voltage is about 9 KV at nitrogen pressure 45 Torr. The pressure dependence of the laser output has been measured as a function of gas pressure and optimum peak condition is obtained as 35 Torr at 12 KV, 45 Torr at 16.4 KV, respectively.

It is found that the pulse repetition (x) dependence of the laser output (I) is represented by the simple relation $I=Ae^{-ax}$. The directivity of the lasing beam is 23 mrad in the horizontal and 4 mrad in the vertical direction. Because of the short pulse duration of N_2 laser, the life time of green fluoresence ($^5D_4-^7F_5$) of Tb^{3+} glass was measurable and was determined to be 643 μsec.

The fractal expression $I=AP^{\pm\alpha}$ for the relation between laser power (I) and gas pressure (P) is adopted, for the first time, in the laser field. [For example, $A=2.5\times10^{-4}$, $\alpha=3.6$ for 12 KV (~35 Torr) and $A=2.4\times10^{-2}$, $\alpha=2.1$ for 16 KV (~40 Torr).]

1. Introduction

The success of nitrogen lasers has stimulated studies on sharp optical transitions of impurity ions in crystals and glasses or amorphous materials. The nitrogen laser action was first discovered by Head (1963)[1]. Since the discovery of laser action from the electronic transition of nitrogen in the second positive band, a considerable amount of studies, both theoretical and experimental, have been done in this field, and then the laser has been widely used as a pump source for tunable dye lasers (Aussenegg and Leitner 1980)[2].

The laser transition occurs between the lowest vibrational levels of the $C^3\Pi_u$ and $B^3\Pi_g$ levels of the second positive system of the N_2 molecule (See Fig. 1)[3]. Since the life−time of the upper state is very short ($\simeq$40nsec) compared with the lower state

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($\simeq 10\mu$sec) (Ali 1969)[4], an inversion population can only be achieved using a fast discharge.

A parallel plate Blumlein–type[5][6] structure shunted by a spark gap is usually used to obtain a fast transverse discharge. Within the last few years new techniques for operating crossed–field superradiant pulsed lasers have been developed using a low–impedance pulse–forming network (the so–called Blumlein pulse generator) in tne form of a parallel–plate transition line (Shipman 1967[7], Tarasenko et al 1973)[8]. Trying to increase the output power, several investigators have studied the effect of additives (Mehendale and Bhawlkov 1982[9], Atkins and Lin 1976)[10] and electrode profile (Rebhan et al 1980[11], Lal and Thakur 1982)[12] on the performance of N_2 lasers.

In this article, the dependence of the output energy on the exciting voltage, nitrogen gas pressure, pulse repetition rate and beam directivity are presented and discussed. Moreover, the optimum pressure condition for maximum output energy is described.

Finally, the decay time of the Tb^{3+} ion in glass is obtained and it is shown that the pulse repetition dependence of the laser output power is represented by the relation $I=Ae^{-ax}$ and also the laser output energy associated with gas pressure is expressed by the fractal dimension of nature $I=\beta P^{\pm\alpha}$.

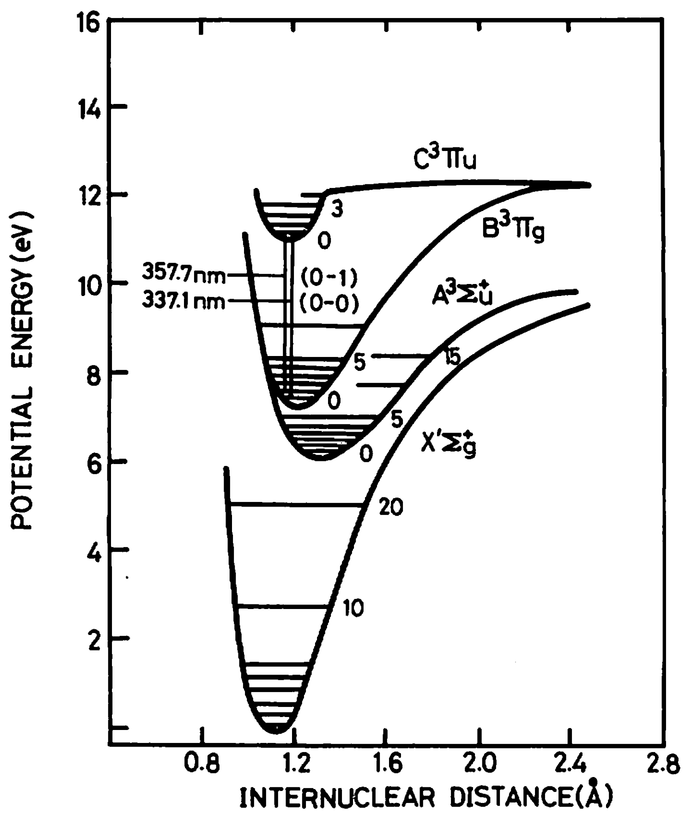

Fig.1 Energy level diagram for the nitrogen molecule in the first and second positive bands. The laser action occurs between $C^3\Pi_u$ and $B^3\Pi_g$ (0–0) at 3371Å.

2. Experimental Device[6,13]

To obtain laser action in the second positive band system ($C^3\Pi_u \rightarrow B^3\Pi_g$) of molecular nitrogen, the rise time of the excitation current should be short enough with respect to the radiative life time of the $C^3\Pi_u$ level ($\simeq$40nsec)[14,15]. A laser device consists mainly of the laser channel, power supply, trigger circuit and vacuum system.

2–1. Laser Channel and Power Supply

The laser tube has an active length of 930mm, cross section of (30×20)mm², and the discharge electrodes are made of 5mm thick and 40mm wide aluminum plates. The electrode separation is 25mm. The capacitos were arranged with each side consisting of 22 (1000pF) capacitors, at a separation of 43mm. One end of the laser channel was sealed by a plane mirror, the other by a quartz–glass window. Nitrogen gas was let in at one end of the tube and pumped out at the other end (See Figs.2 and 3).

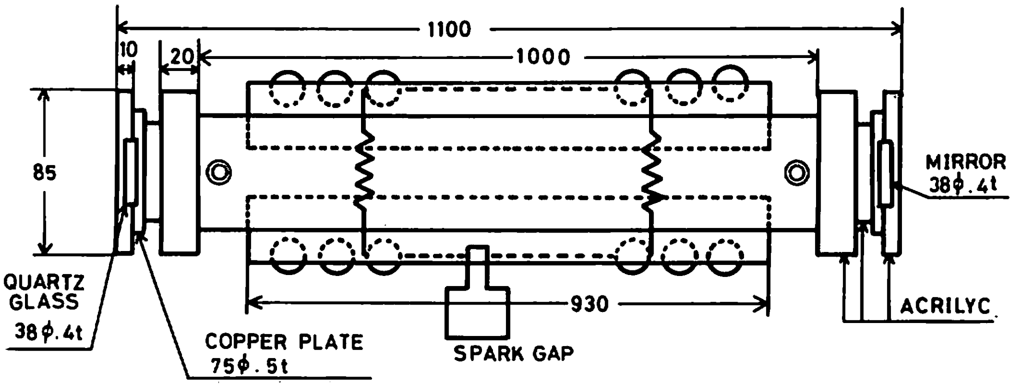

Fig.2 Top view of the scaled–up ceramic capacitor Blumlein–type N_2 laser. It has an active length of 93cm, cross section of (3×2)cm², electrode separation of 2.5cm and 44 (1000pF) capacitors..

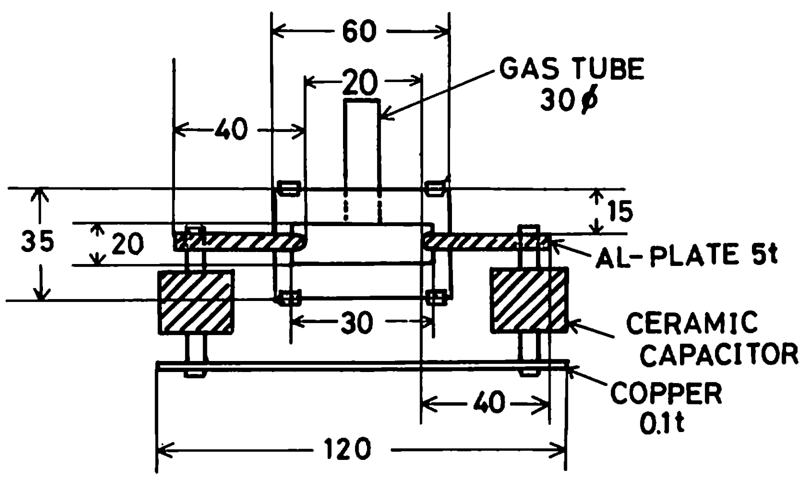

Fig.3 Cross section of the scaled–up N_2 laser. The capacitors are arranged with separation of 4.3cm. The discharge electrodes are made of 5mm thick, 40mm wide and 930mm long aluminum plates.

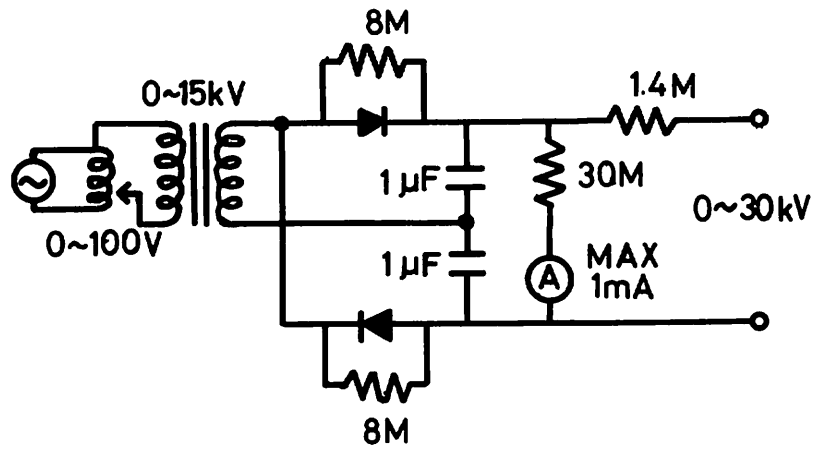

Fig.4 Power Supply Circuit. This gives a maximum output of 30KV using a 15KV neon transformer and voltage doubler. The output voltage is adjusted by a slidac.

To keep a high vacuum, all seals between connected parts were made of silicon rubber (KE–45RTV). A commercially available nitrogen gas was used. The power supply for the laser gives a maximum output of 30KV using a 15KV neon transformer and voltage doubler. The output voltage is adjusted by a slidac and measured with an ammeter. Figure 4 shows the circuit diagram of the laser power supply.

2–2. Trigger Spark Gap

A spark gap is located near the center of the laser tube. The ignition coil circuit and pulse circuit form the trigger pulse circuit. The ignition coil circuit and pulse circuit are connected by a relay. The trigger pulse frequency can be varied by adjusting the pulse rate of the pulse circuit (See Figs. 5, 6, 7).

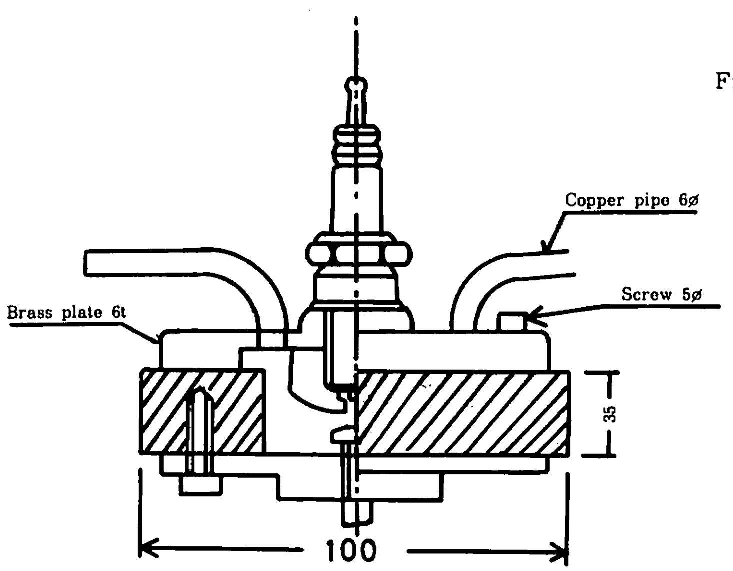

Fig.5 Detail of Spark Gap. The electrodes of the spark gap are made of brass and are rounded–off. The gap is adjusted by the lower screw.

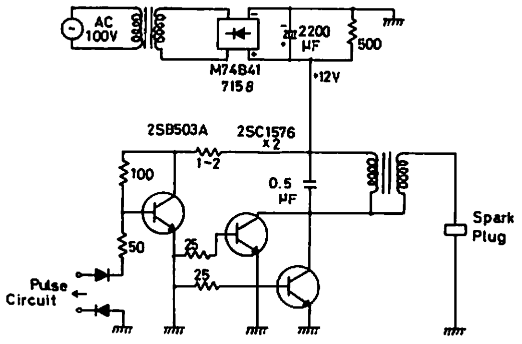

Fig.6 Ignition Coil Circuit.

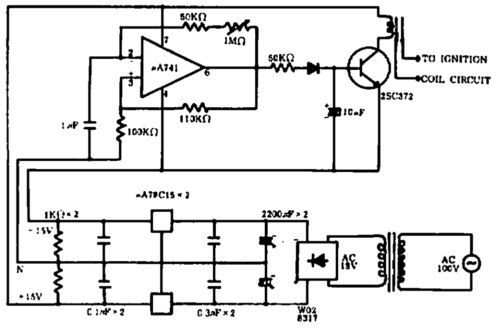

Fig.7 Pulse Circuit. The pulse rate is varied to a maximum pulse rate of 20Hz. The pulse circuit and ignition coil circuit are connected by a relay and form the trigger pulse circuit.

3. Experimental Results and Discussion

To measure the laser output power, we made a circuit as in Fig.8(A) using a photo-transistor (TPS-605). The measurement procedure is as follows: the nitrogen laser beam hits the metaphosphate terbium glass [$Ca(PO_3)_2$:Tb^{3+}] which emits green light. The emitted light is accepted by a photo-transistor and amplified by a pulse amplifier.

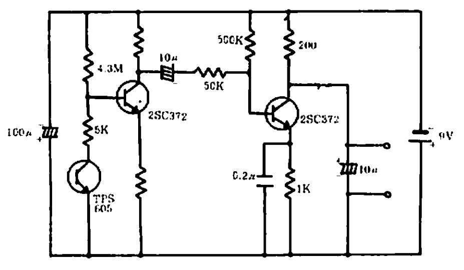

Fig.8 (A)

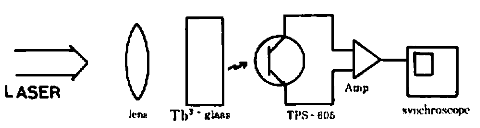

Fig.8 (B)

Fig.8 Circuit diagram and optical system for laser output measurement. The condensed laser beam hits the metaphosphate terbium glass which emits green light. The emitted light is accepted by a photo-transistor and amplified by an amplifier. The amplified output is diplayed on a synchroscope.

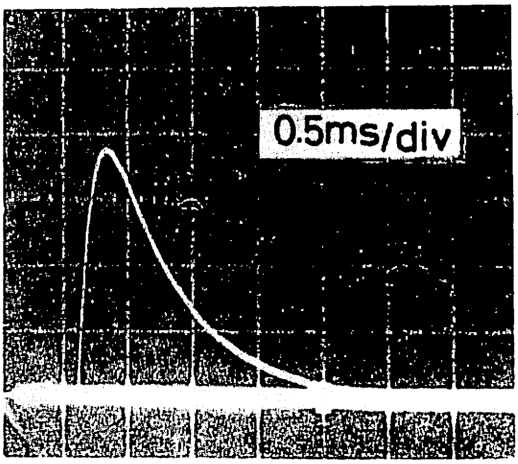

Fig.9 A Typical Wave Form Oscillogram. This is a typical wave form oscillogram of the metaphosphate terubium glass [Ca $(PO_3)_2$:Tb^{3+}]. It is taken at wave-length 546nm ($^5D_4 \rightarrow {}^7F_5$ transition) and the determined life time is 643μsec.

The amplified output is displayed on a synchroscope. Fig.8(B) is the optical system for laser power measurement. Fig.9 shows a typical wave form oscillogram of the glass emission at wavelength 546nm ($^5D_4 \rightarrow ^7F_5$ transition, life time of 643μsec). The value of the output power was taken as an average of measured values.

3-1. Applied Voltage Dependence

Fig.10 shows the laser output power as a function of applied voltage. Measurements were made at pressure 55 Torr and 35 Torr, respectively. It is obvious that the output is proportional to the applied voltage and the threshold increases as pressure increases.

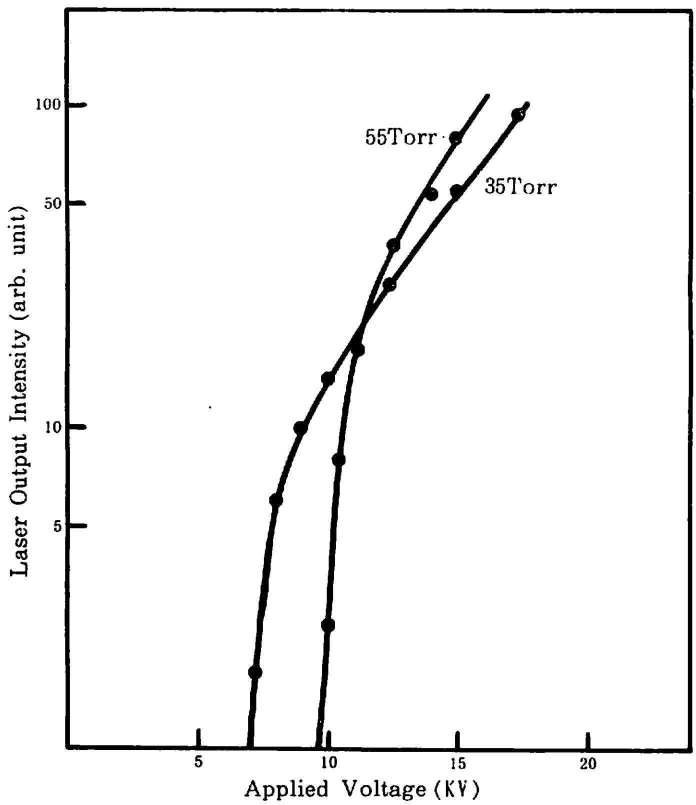

Fig.10 Laser output power versus charging voltage for pressure 55 and 35 Torr respectively. It is shown that the threshold increases as pressure increases and the output is proportional to the charging voltage.

3-2. Pressure Dependence

Fig.11 shows the laser output power as a function of nitrogen gas pressure. As shown in Figure 11, there are upper and lower limits for laser oscillation and as the applied voltage is increased, the oscillating region increases. Measurements were made at charging voltages of 16.4KV and 12KV, and the optimum pressures were found to be 45 Torr and 35 Torr, respectively.

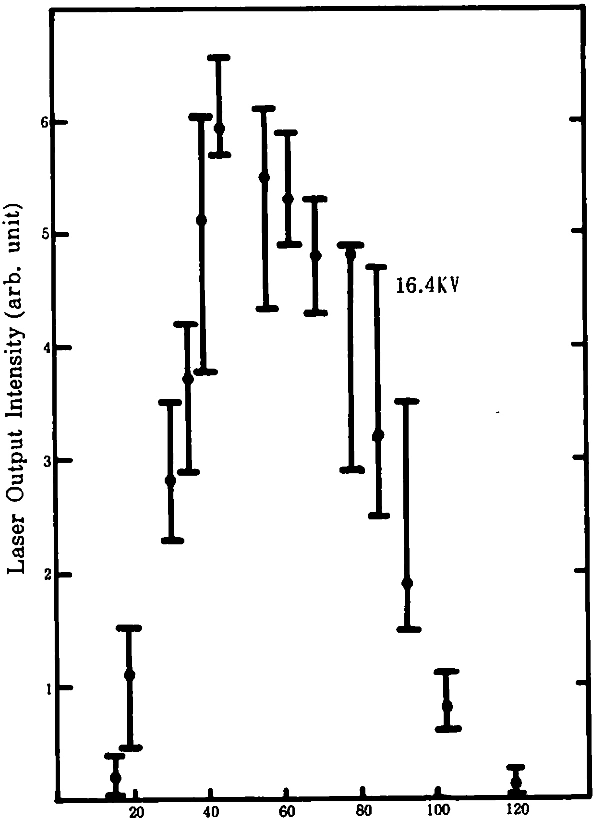

Fig.11 (i)

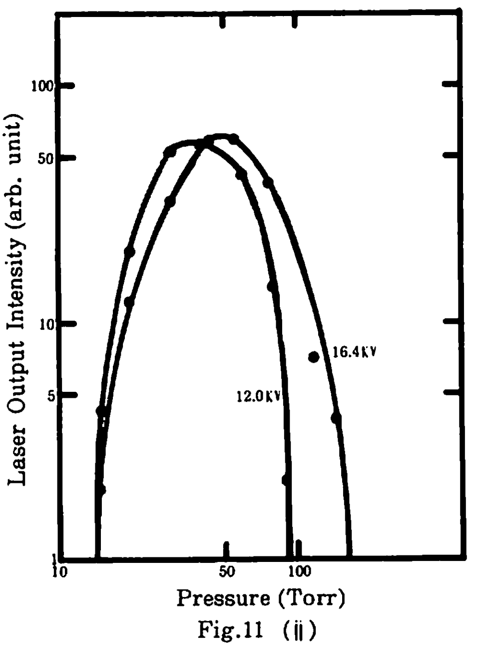

Fig.11 (ii)

Fig.11 Laser output power versus pressure for applied voltage 12 and 16.4 KV respectively.

i) linear scale for 16.4 KV.

ii) logarithmic scale for 16.4 KV and 12 KV.

The optimum pressure and oscillating region increases as charging voltage increases. The oscillating region and the optimum pressure are 15~120 Torr, 45 Torr at 16.4 KV and 15~90 Torr, 35 Torr at 12.0 KV respectively. The curves for 16.4 KV and 12 KV could be approximated by the fractal relation $I = AP^{\pm\alpha}$ between laser power (I) and pressure (P).

To formulate an equation for the curve in Fig.11(ii), we assumed an equation of the form $I=AP^{\pm\alpha}$ between output (I) and pressure (P), where A and α are constants. However, the curve for 16KV could be approximated by two sets of constants, and the curve for 12KV by three sets of constants. As the results, A, α, and the equation were determined as follows, at 12KV, $I=-2.5\times10^{-4}P^{3.6}$ (~35 Torr), $I=2.1\times10^{36}P^{-18.4}$ (35~70 Torr), and $I=1.7\times P^{-0.94}$ (70 Torr~) and at 16.4KV, $I=2.4\times10^{-2}P^{2.07}$ (~40 Torr), and $I=5.5\times10^{8}P^{-3.74}$ (86~120 Torr).

3–3. Repetition Rate–Dependence

The output powers as a function of pulse rate are shown in Fig.12. It can be seen that the output decreases as the pulse rate increases. Let I and x denote output and frequency respectively, and if we assume the relation $I=Ae^{-ax}$, the experimental

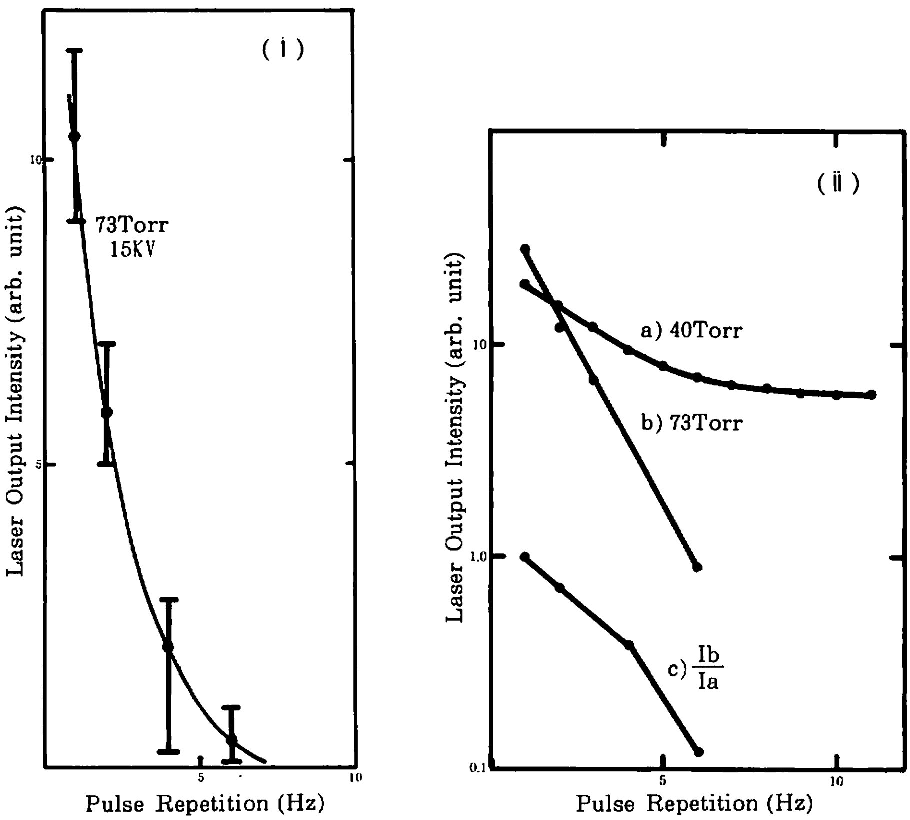

Fig.12 Output power as a function of pulse rate.
i):linear scale for 73 Torr ii):logarithmic scale for a) 73 Torr, b) 40 Torr and c) the ratio of the laser output at 40 Torr and 73 Torr. To analyze the experimental results, we assumed the relation $I=Ae^{-\alpha x}$ between output (I) and pulse rate (x), where A and α were constants. We determined the constants as follows: at 40 Torr $I=23.6e^{-0.23x}$ $(1\leq x\leq5)$ and $I=9.5e^{-0.05x}$ $(5\leq x\leq11)$ at 73 Torr $I=49.6e^{-0.67x}$. These equations are fitted well for experimental results.

results can be fitted well. The results were, at 15KV, 40 Torr $I=23.6e^{-0.23x}$ ($1\sim5$Hz) $I=9.5e^{-0.05x}$ ($5\sim11$Hz) and at 15KV, 73 Torr $I=49.6e^{-0.67x}$

Furthermore, the ratio of the output at 40 Torr to the output at 73 Torr is shown in Figure 12 (ii). It is shown that the ratio decreases as the pulse rate increases. Thus low pressure operation will give a high power output at a high pulse repetition rate.

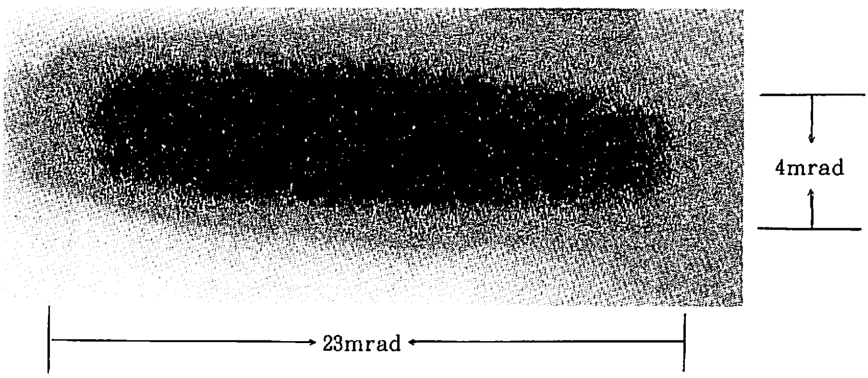

Fig.13 Far field pattern photograph of the laser output. The size is $(9.2 \times 3.0)cm^2$ at a distance of 3m. The divergence is 4 mrad in the vertical and 23 mrad in the horizontal plane.

3–4. Directivity

Fig.13 gives the far–field pattern photograph of the laser output. The beam divergence was calculated by the linear dimensions of photographs. It is obtained to be 4 mrad in the vertical and 23 mrad in the horizontal plane.

The result can be compared with the result of Schoefer et al (13×33 mrad)[5]. The directivity can be improved with more careful alignment of the mirrors.

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