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PULSE WIDTH OF NITROGEN LASER DEPENDING ON PRESSURE, A REPETITION RATE ELECTRODE SEPARATION

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ABSTRACT

In the typical Blumlein-type nitrogen laser, the dependence of laser pulse width on pressure, a repetition rate and electrode separation is discussed. As the pressure increases, the pulse width decreases owing to the increase of the discharge channel resistance. The repetition rate of the laser pulse is adjusted by using a thyratron as a trigger switch. The pulse width increases with the increasing repetition rate. When the repetition rate exceeds a certain threshold, the laser emission stops. This reason is discussed with respect to a destruction time of metastables of nitrogen molecules. The effects caused by changing electrode separation and adding the third electrode are also discussed. The third electrode makes the pulse width short by pre-ionization.

§ 1. Introduction

A nitrogen laser has been utilized as a useful light source, since it was devised by Heard (1963). Its laser emission is obtained as repetitive pulses of several nano seconds in width and the peak power ranges from the order of kW to MW depending on devices. In the first stage, all devices are the co-axial type. The first transverse electrical excitation type was reported by Leonard (1965). Since a Blumlein-type was reported (*Shipman* 1966), many designs of this type have been developed to get high efficiency. When the laser is used as a pumping light, the short pulse is more useful than the long one. It was considered that the pulse width depends on pressure and electrode separation (*Bergmann* 1977 ; *Hasson* 1975). A repetition rate is also considered to influence the pulse width because it takes a certain time for the discharge channel to recover its normal state after a discharge (*Targ* 1972). In this paper, we report the dependence of the pulse width on pressuse, a repetition rate and electrode separation with the third electrode using typical Blumlein-type N_2 lasers.

§ 2. Experiment

In this study, we constructed two kinds of N_2 laser devices. One of them operates at the pressure of 50–150 torr having the output power of 5 kW, and the other operates at the atmospheric pressure having the output power of 2 kW. The former was used for the measurements of the dependence on pressure and a repetition rate, and the latter was for the dependence on electrode separation. The structure of the latter is described in Fig. 1. The electrode separation can be adjusted by two screws. The structure of the former is similar to that of the latter, but the discharge channel is airtight and the electrodes are fixed with the separation of 15 mm. For a discharge trigger, a spark gap is usually used. However it is difficult to set the repetition rate precisely by adjusting the spark gap. Therefore we used a thyratron (ITT 2G22P) for the discharge trigger in the measurement about the repetition rate dependence.

The laser output was monitored by an HTV R-617 biplaner photocell having a rise time of 0.5 ns, and the output of the photocell was fed through 50 ohm cables into a Tectronix-485 oscilloscope having a rise time of 1 ns. The pulse form on the oscilloscope was photographed and FWHM (Full Width at Half Maximum) was measured. The form of laser pulses of both laser devices is shown in Fig. 2. In this paper, the pulse width always means FWHM of the pulse.

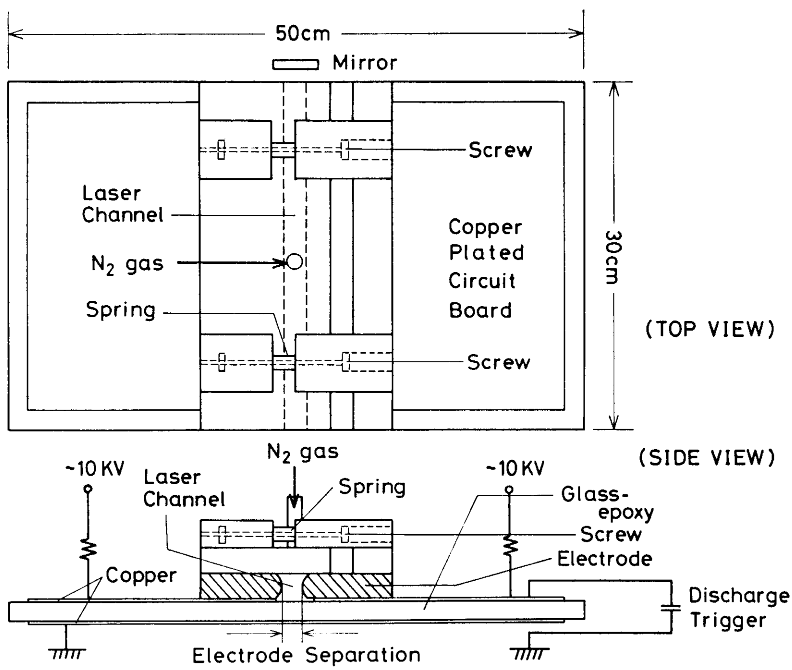

Fig. 1. The structure of the atmospheric N_2 laser. The Blumlein circuit is made up of a cupper plated glass epoxy board of 1 mm in thickness. The electrodes, of which separation is adjustable by screws, are made of aluminium.

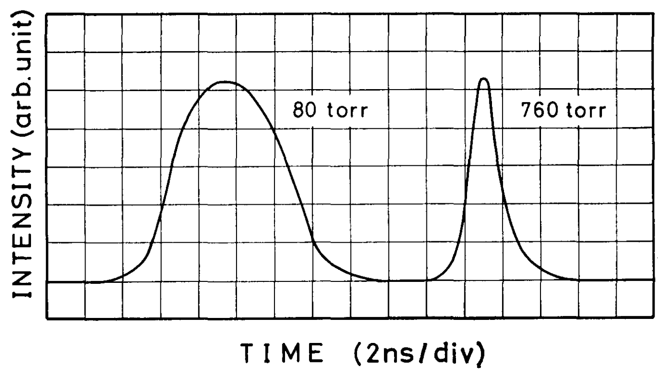

Fig. 2. Photographed laser pulses. The left one is of the low pressure laser and the right one is of the atmospheric laser.

§ 3 Basic Theory of the Blumlein Circuit

The Blumlein circuit consists of two transmission lines, a discharge channel and a trigger switch. The equivalent circuit is shown in Fig. 3 (*Murakami et al.* 1976).

Many studies have been done to get high efficiency of the laser output (*Schmidt* 1977; *Leonard* 1965). The main parameter for the efficiency is the value of E/P (E is the electric field in the discharge channel and P is the pressure in the channel). Many other parameters have been reported which influence the output efficiency, *e.g.* the structure, the electrode separation, the velocity of N_2 gas flow, the purity of N_2 gas and various parameters in a driving circuit. The time variations of the voltage between the electrodes, the discharge current and a laser output pulse are shown in Fig. 4 (*Schwab et al.* 1976; *Ishida et al.* 1977). Both transmission lines, which constitute capacitors respectively, are charged up to V_0 volts until $t=t_0$. When the trigger switch S is closed at $t=t_0$ a voltage wave excited at the trigger switch transfers on the transmission lines to the electrode and the discharge begins from one end of the electrode to the other end successively. The rise time

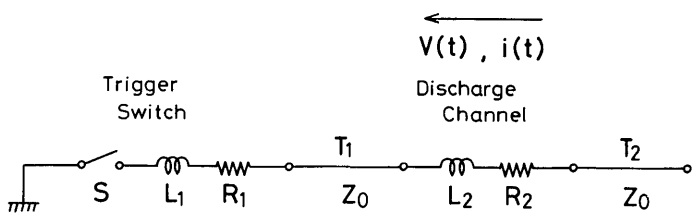

Fig. 3. Equivalent circuit for the Blumlein system. L_1, L_2, and R_1, R_2 are inductances and resistances respectively. Suffixes 1 and 2 correspond to the trigger switch and the discharge channel, respectively. T_1, T_2 are the transmission lines having characteristic impedance of Z_0. The discharge channel is placed between two transmission lines, and S is the trigger switch for discharge. $V(t)$ and $i(t)$, which are time dependent, are the voltage between electrodes and the discharge current, respectively.

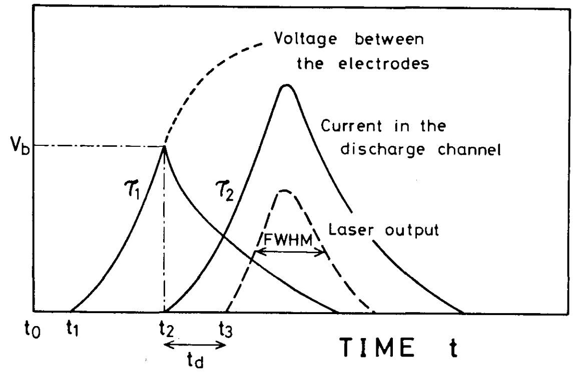

Fig. 4. Time variation of voltage, current, and a laser output pulse. Trigger discharge occurs at $t=t_1$ and the voltage wave rises with a rise time τ_1. When the voltage reaches to V_b and the main discharge occurs at $t=t_2$, the discharge current rises with rise time τ_2. Laser pulse is emitted at $t=t_3$ with delay time t_d.

of the voltage at the electrode τ_1 is presented by (*Murakami et al.* 1976)

$$\tau_1=\tau_{01}+\frac{L_1}{R_1+Z_0}\ , \tag{1}$$

where L_1, R_1 and Z_0 should be referred to Fig. 3 and τ_{01} is the forming time of the voltage wave at the trigger switch. In order to decrease L_1, many designs of the trigger switch have been developed (*Small et al.* 1972; *Hasson et al.* 1975; *Saikan et al.* 1975). The characteristic impedance Z_0 can be calculated as follows (*Murakami et al.* 1976).

$$Z_0=\frac{377s}{\sqrt{\varepsilon_r}\,d}\ , \tag{2}$$

where s and d are the thickness and the width of the transmission lines which consist of capacitor boards and ε_r is the relative dielectric constant of the capacitors. The calculated value of Z_0 in our device is 0.74 Ω. When the voltage between the opposite electrodes reaches to the threshold V_b, the discharge occurs in the discharge channel. This discharge causes a current pulse with a rise time of τ_2 which is represented by

$$\tau_2=\tau_{02}+\frac{L_2}{R_2+2Z_0}\ , \tag{3}$$

where L_2, R_2 and Z_0 should be referred to Fig. 3 and τ_{02} is the forming time of the discharge current. The output laser pulse is emitted following to this current pulse having a delay time of t_d.

§ 4. Results and Discussion

4.1. Dependence on pressure

Dependence of the pulse width on pressure is shown in Fig. 5. The laser emission stops at the pressure over 150 torr. Though the electrodes of our laser is fixed with the separation of 15 mm, the pressure threshold for the laser operation is expected to increase by bringing both electrodes closer. The pulse width decreases with increasing pressure. A rise time of the current pulse is obtained by eq. (3). The resistance of a discharge channel R_2 is considered to be the infinity before a discharge, and it becomes a function of time after an onset of the discharge. It is assumed that the value of R_2 increases with increasing pressure. Therefore the higher the pressure is, the shorter pulse can be obtained. However we could not describe the exact discharge process such as an arc discharge, a glow discharge etc., so that it is difficult to obtain the value of the impedance in the discharge channel. In this way, the dynamic analysis of the discharge mechanism during a short time of laser emission is very complex and it is difficult to make a mathematical expression for the dependence of pulse width on pressure.

4.2. Dependence on a repetition rate

Using a thyratron instead of a spark gap, pulse widths at various repetition rates were measured. The results for three different values of pressure are shown in Fig. 6. In each pressure, the pulse width increases with the increasing repetition rate, and the laser emission stops at a certain repetition rate.

Just after a discharge, there are many metastables and electrons in the discharge channel. If they were not removed before the next discharge, they would

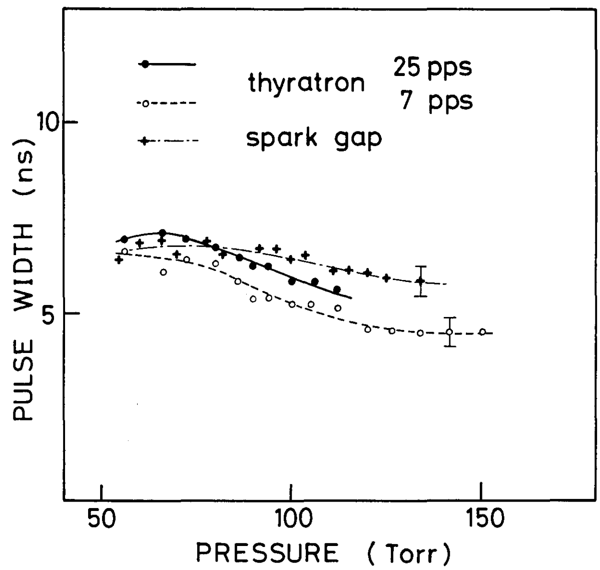

Fig. 5. Dependence on pressure using the low pressure laser. Electrode separation: 15 mm, charge voltage: 7 kV and laser output power: *ca.* 5 kW.

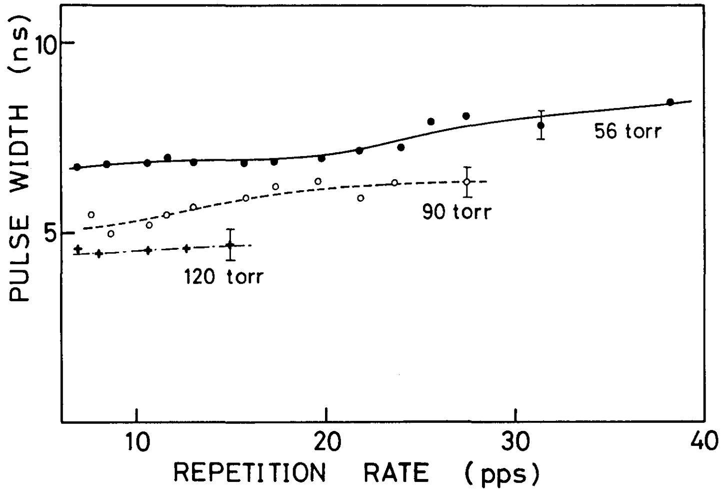

Fig. 6. Dependence on a repetition rate using the low pressure laser. Electrode separation: 15 mm, charge valtage: 7 kV and laser output power: *ca.* 5 kW. The right ends of three curves correspond to the threshold values of the repetition rate for each pressure.

degrade the uniformity of the electrical discharge. The destruction time of them is considered to be primarily controlled by the diffusion time of the metastables to the channel walls. This time is given by the following equation (*Targ* 1972).

$$\tau_d = \frac{4d^2}{\pi^2 \lambda c} , \tag{4}$$

where d is a dimension across which diffusion occurs, λ is a mean free path and c is a thermal velocity. The maximum repetition rate R_{max} is obtained as the reciprocal of τ_d. The maximum repetition rate of 100 kpps was obtained by the method of flowing N_2 gas in a supersonic velocity (*Wilson* 1966). The relation between the mean free path λ and the pressure P is given by

$$\lambda = \frac{kT}{4\pi\sqrt{2}\, Pr^2} , \tag{5}$$

where k is Boltzman constant, T is temperature, and r is a radius of molecule. From eq. (4) and (5), the following equation is obtained.

$$R_{max} = \frac{1}{\tau_d} = \frac{\pi kTc}{16\sqrt{2}\, Pr^2 d^2} . \tag{6}$$

In our laser, the cross section of the discharge channel is approximately a rectangular of 10 mm×15 mm. Defining d=10 mm, and using the same values of T, c and r as the values in reference 14, the values of R_{max} for each pressure P are calculated. In Table 1, the comparison between experimental R_{max}'s, which are obtained from Fig. 6, and calculated R_{max}'s from eq. (6) is shown. In this calculation, the temperature is assumed to be constant and not to depend on the repeti-

Table 1. The experimental and calculated R_{max}'s. The former is obtained from an operational threshold in Fig. 6 and the latter is calculated from eq. (6).

	120 torr	90 torr	56 torr
Experimental R_{max}	15	27	38
Calculated R_{max}	11	15	24

tion rate. Practically the temperature is considered to increase with the increasing repetition rate, because the thermal energy accumulates in the discharge channel at the high repetition rate. As considering the increase of temperature, the calculated value of R_{max} at the high repetition rate must be corrected. It is clear from eq. (6) that this correction makes R_{max} increase. Therefore it is expected that the corrected R_{max}'s are closer to the experimental R_{max}'s than the pre-corrected values are. In Table 1, both values agree on their order, even though d is defined as the inaccurate value of 10 mm and the change of temperature is neglected. From this result the operational threshold in Fig. 6 can be explained by eq. (6), and it is considered that the increases of the pulse width in the high repetition rate relates to the dynamic condition of discharge.

4.3. Dependence on electrode separation

The dependence of the pulse width on the electrode separation is shown in Fig. 7. In this measurement, we used an atmospheric laser in which the electrode separation is adjustable. The pulse width is very short comparing with the low pressure laser. In the case of the small separation of below 1.5 mm, the pulse

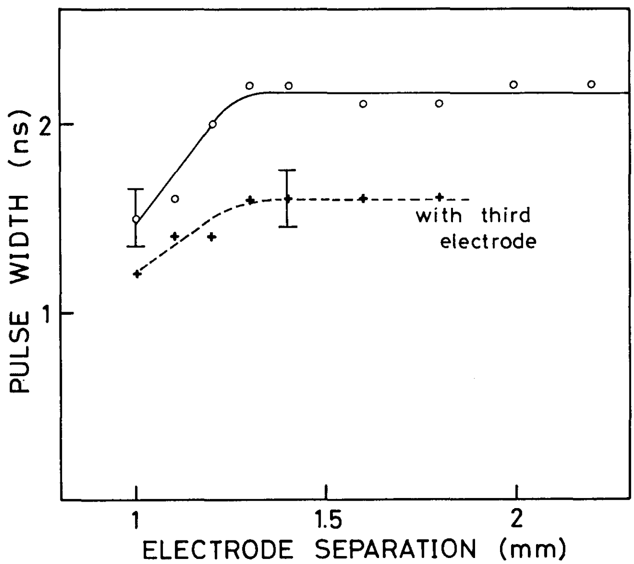

Fig. 7. Dependence on the electrode separation using the atmospheric laser. Pressure: 760 torr, charge voltage: 5 kV and laser output power: *ca.* 2 kW.

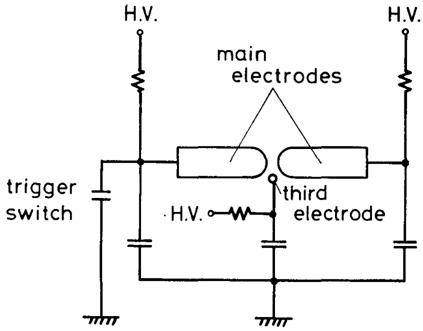

Fig. 8. Schematic circuit of the laser containing the third electrode which is made of an iron wire of 0.8 mm in diameter.

width decreases as the decreasing distance. The output of the atmospheric laser with the third electrode was also measured. The third electrode is made of an iron wire of 0.8 mm in diameter. The position of this electrode is shown in the schematic circuit of Fig. 8. The pulse width of the laser with the third electrode is always shorter than that without it. The dependence of the output power on the electrode separation (*Bergmann* 1976) and the third electrode (*Levatter* 1974) have been reported, but the theoretical analysis of this dependence has not been made. The third electrode is considered to make pre-ionization before the main discharge so that it makes the discharge forming time τ_{02} short and then the pulse width short.

§ 5. Conclusions

Using the typical Blumlein type N_2 laser devices, dependence of pulse width on various experimental conditions is confirmed as follows.

1. The pulse width decreases with increasing pressure. This reason is considered to be the increase of resistance of the discharge channel.
2. The pulse width increases with an increasing repetition rate. There is an upper threshold of the repetition rate for the laser emission, and this threshold is lower in high pressure than in low pressure. This threshold depends on a destruction time of metastables of nitrogen molecules.
3. The pulse width depends on the electrode separation. The third electrode is considered to shorten the discharge forming time because of the pre-ionization and then to make the pulse width short.

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