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# High repetition rate atmospheric pressure $N_2$ laser*

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The atmospheric pressure $N_2$ laser with repetition rate up to 500 Hz, pulse duration shorter than 500 ps and pulse energy up to 100 μJ has been constructed. Dependence of laser pulse parameters on the shape of electrodes, their separation and inclination angle is reported.

## 1. Introduction

First $N_2$ laser worked at nitrogen pressures of several Torr, which resulted in pulse duration of a few nanoseconds [1]. Operation at atmospheric (and higher) pressure has been proposed by Kurnit et al. [2]. Under such conditions – due to very high quenching rate of the upper laser level – the time decay of the fluorescence at 337.1 nm strongly decreases and the pulse duration becomes shorter than the transit time through a laser channel. As a result the laser pulse duration depends only on the length of the laser channel. In order to avoid this limitation Strohwald and Salzmann [3] used a technique of a travelling-wave excitation. With the electrode separation increasing along the channel, the electrical breakdown in the gas occurs at different times in different points. By choosing the proper inclination angle between the electrode plates one can obtain an excitation wave travelling along the channel with the velocity close to that of light. It allowed to get pulse duration of about 300 ps at a repetition rate of 100 Hz [4]. Such a laser can act as a pump for a dye laser with a very short cavity making it possible to obtain dye laser pulses several times shorter than the pumping pulse [4].

In the present paper we describe the construction of the atmospheric pressure $N_2$ laser of pulse duration and energy comparable to those reported before. However, by applying transverse nitrogen flow through the laser channel and recirculation system we succeeded in getting considerably higher repetition rates. The dependence of laser pulse parameters on electrode separation and curvature radius of electrode edges was studied systematically.

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## 2. Constructions of laser channel and experimental set-up

Figure 1a shows a cross-section of the laser channel. Two symmetrical aluminium electrodes of dimensions $40 \times 6 \times 0.8$ cm$^3$ (1) and a 0.25 mm Mylar foil (2) are placed on a metal base (3). Edges of the electrodes are rounded, their curvature radius being changed during measurements from about 0.5 to 2 mm. A mechanical arrangement (omitted in the Figure) allows to alter the separation between electrodes and the angle of their inclination. Both the electrodes are situated in plaxiglass box (4) into which atmospheric pressure nitrogen is supplied. A blower (5) with a specially shaped opening (6) and driven by an electric motor causes recirculation of nitrogen by pressing the gas between electrodes and then, through several holes cut out in electrodes (7), to the upper part of the laser channel. Such a construction enables extremely rapid nitrogen flow, transverse to the direction of the laser beam, permitting the complete exchange of the gas in the discharge region between two successive laser pulses.

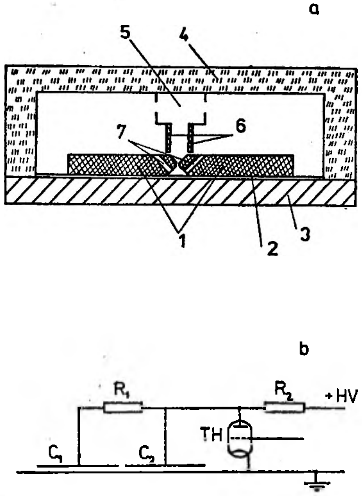
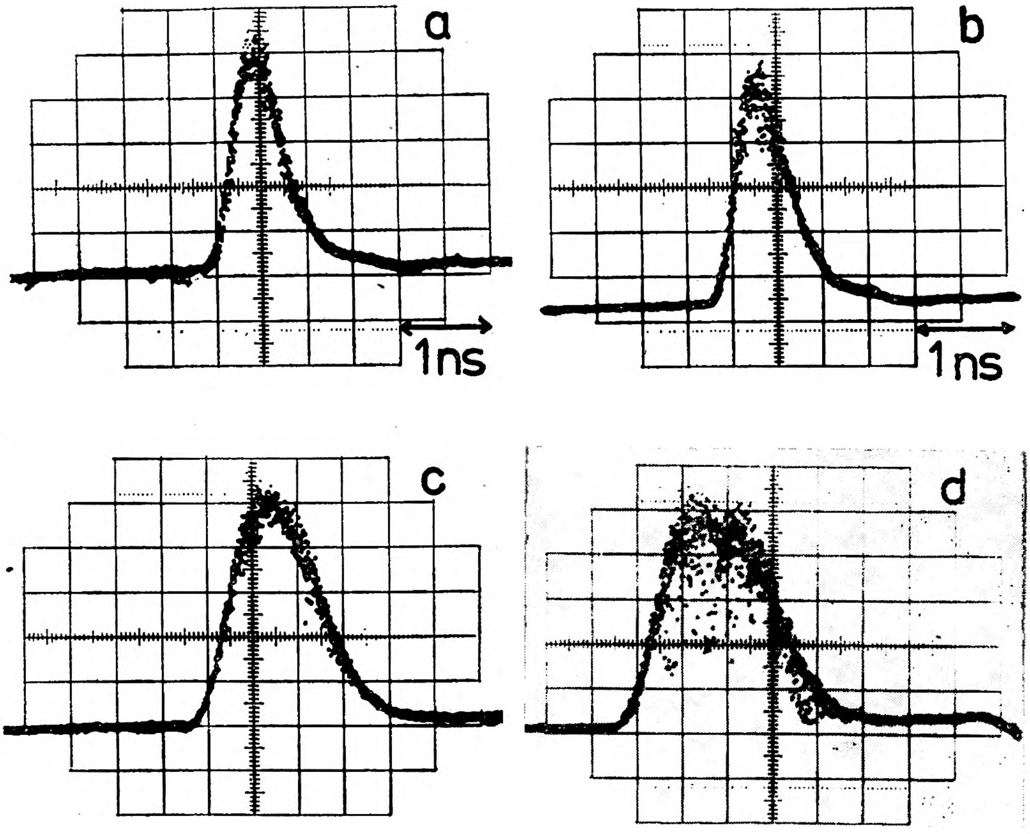


Fig. 1. Cross-section of the laser channel (a), electric circuit of the laser (b). For all descriptions see the text

Schematic diagram of the laser electric circuit is shown in Fig. 1b. $C_1$ and $C_2$ (about 2 nF each) are capacitances between the electrodes and the base. Both of them are charged to a high voltage through resistors $R_1 = 10\ \Omega$ and $R_2 = 200\ \mathrm{k}\Omega$. During our measurements charging voltage was fixed at 18 kV. When a thyratron (TH) is short-circuited, the capacitance $C_2$ unloades rapidly (several ns). A potential difference equal to the initial voltage is then produced between electrodes and a gas discharge builds up in the laser channel. Since at atmospheric pressure of nitrogen the discharge time is longer than unloading time of capacitance $C_2$, there is no reason to minimize inductance of the $C_2$-TH circuit. The use of the hydrogen thyratron makes it possible to obtain a high repetition rate of electric pulses (up to 1 kHz).

In the experiment the energy of the laser pulses was measured by Laser Precision Corp. model RK 3232 energy meter. The laser pulse duration was monitored with a vacuum photodiode and 10 GHz sampling oscilloscope. The risetime of the measuring system was estimated as about 150 ps. The results were either photographed directly or averaged using the PAR model TDH-9 waveform eductor.



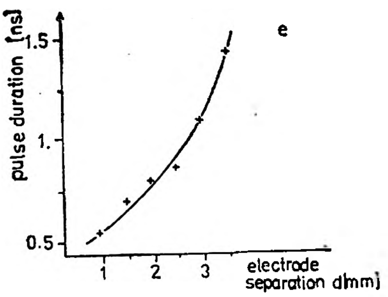


Fig. 2. Laser pulse shape for various electrode separations: 1 mm, 2 mm, 3 mm and 3.5 mm at fixed curvature radius of electrode edges $r = 1$ mm (a–d). FWHM of the laser pulse vs. electrode separation at $r = 1$ mm. No correction for apparatus risetime has been made (e)

## 3. Results

Several sets of measurements of the laser pulse shape, corresponding to various curvature radii of electrode edges, were performed while in each set the electrode separation was changed. For each separation the angle of inclination between the electrodes (about $2.5 \times 10^{-4}$ rd) was chosen to minimize the pulse duration. Such a configuration corresponds to the situation in which the wave of excitation travels along the laser channel with the velocity of light. This was confirmed by observation of unidirectional laser emission in the direction of increasing electrode separation (the ratio of laser energy emitted in opposite directions was about 20 : 1). However, it was possible only for small electrode separation. For larger separation the pulse duration did not depend on the inclination angle between the electrodes and was determined by the length of the laser channel.

We have found that the pulse duration depends on the curvature of electrode edges as well as on the separation between them. For a fixed curvature the pulse shape changes with electrode separation, as shown in Figs. 2a–d. A half-width of the pulse as a function of electrode separation is presented in Fig. 2e. Taking into account the risetime of our detection system the pulse duration of the presented construction is similar to that reported previously [3, 4]. As it is seen in Figs. 2a–e, for large electrode separations, when the pulse duration equals approximately to the transit time through the laser channel, there is no travelling-wave discharge. It can be caused by a lower intensity of electric field between the electrodes and a greater inductance of $C_1$–$C_2$ circuit. For a fixed electrode separation the laser operation depends essentially on the curvature radius $r$ of electrode edges since the laser pulse duration increases slightly with the increasing $r$, while for small $r$ an intense sparking between electrodes is observed. As a result the laser pulses are drastically less reproducible as far as their amplitudes and widths are concerned (Fig. 3).

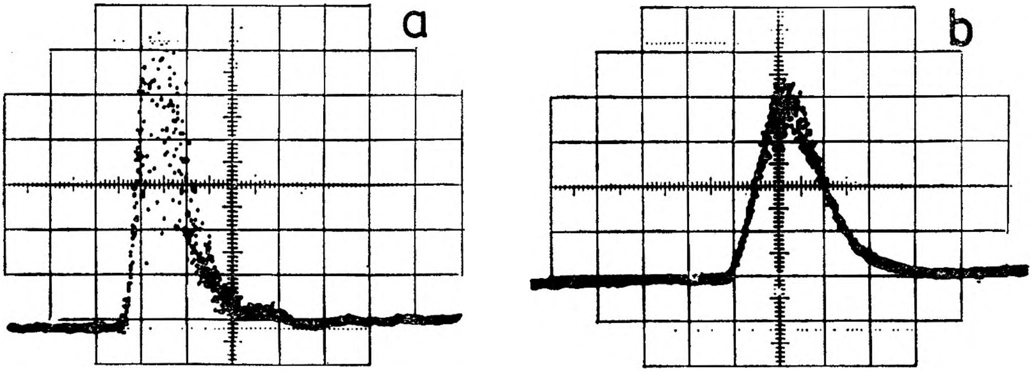


Fig. 3. Comparison of laser pulse recorded on sampling oscilloscope for various curvature radii of electrode edges: $r = 0.5$ (a), $r = 1.5$ mm (b). Electrode separation equals 1 mm in both cases

The laser pulse energy depends only on the electrode separation *d*. This dependence presented in Fig. 4 shows that the energy reaches the maximum value at $d = 2.5$ mm which corresponds to the pulse duration equal to 800 ps.

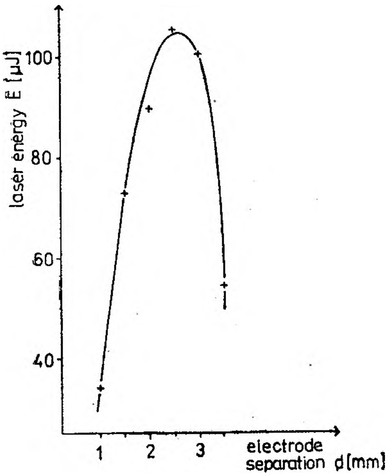


Fig. 4. Laser pulse energy as a function of electrode separation

We have examined also the dependence of the maximum laser repetition rate on the gas flow between the electrodes. With no gas flowing the maximum repetition rate was about 200 Hz for electrode separation $d = 1$ mm and about 100 Hz for separation $d = 2.5$ mm. During the gas flow the corresponding repetition rates increased to 500 Hz and 250 Hz.

## 4. Conclusions

We constructed the $N_2$ laser with the pulse duration less than 500 ps and the repetition rate of 500 Hz, considerably higher than that reported up to now. The laser pulse energy is sufficient to pump a dye laser allowing to obtain subnanosecond laser pulses in the whole visible region and near IR. Moreover, for applications requiring higher energies the laser can be coupled with TE amplifier to get the energy of several mJ [5].

As a result of systematic studies of the pulse parameters (energy, duration) and stability of laser operation as a function of electrode separation and curvature radius of electrode edges, we have found that the laser configuration leading to the shortest pulse duration is different from that leading to the maximum pulse energy. The shortest pulse duration (~500 ps) corresponds to the least distance between the electrodes. The pulse energy is also a function of the electrode separation, but its maximum corresponds to the pulse duration of about 800 ps. The use of very sharp electrode edges allows to obtain slightly shorter pulses but their reproducibility is very poor. For many applications the radius of curvature of about 1 mm seems to be the optimum.

## 5. Example of application

The laser described above was used to study temporal evolution of fluorescence in dense sodium vapours. Using the $N_2$ laser light we excited directly the singlet $C$ state of sodium dimer and observed in emission the violet diffuse band, corresponding to the transition between triplet states in $Na_2$ [6], upper – unidentified bound state, lower being the well known repulsive ground state.

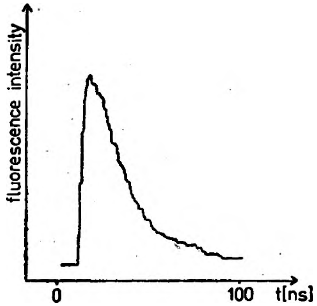


Fig. 5. Time evolution of the diffuse band fluorescence of $Na_2$ recorded at $\lambda = 436$ nm

The upper triplet state was populated due to collisional energy transfer from the singlet $C$ state. Temporal evolution of the diffuse violet band fluorescence is shown in Fig. 5. Using for excitation the laser with pulse duration shorter than 500 ps we could measure with great accuracy the risetime and decay time of the fluorescence, corresponding to the lifetimes of a singlet $C$ state and unidentified upper triplet state. The details of the experiment will be published elsewhere [7].

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## $N_2$ лазер высокой частоты импульсов, работающий в условиях атмосферного давления

Построен азотный лазер, работающий в условиях атмосферного давления, частотой повторения импульсов до 500 Гц, продолжительностью импульса меньше 500 пс и энергией импульса до 100 мкДж. Описана зависимость параметров импульса от вида, расстояния и угла разведения электродов.

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