Discharge stabilization in UV nitrogen laser pumped by longitudinal discharge

I.D. Kostyrya and V.F. Tarasenko

Institute of High-Current Electronics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

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We have investigated the characteristics of the discharge and lasing in nitrogen laser pumped by longitudinal discharge from a generator with inductive energy storage with silicon-on-sapphire (SOS) diode switch. It is shown that use of a specially designed cathode, strengthening the electric field inside a laser tube, allows obtaining a stable lasing in a laser tube of ~49 cm length. We present the amplitude–time lasing characteristics at various nitrogen pressures and cathode shapes.

Introduction

Electro-discharge UV-lasers on molecular nitrogen (second positive system, electronic bands $C^3\Pi_u - B^3\Pi_g$, the strongest transitions: 0–0, λ = 337.1 nm and 0–1, λ = 357.7 nm) have been thoroughly investigated up to now.[1–4] These lasers are rather simple in manufacturing, besides, cheap, non-toxic, and non-aggressive gas is used as an active medium. Therefore, the nitrogen lasers are convenient objects for checking new systems and ways of pumping.

One of such relatively new ways of pumping of pulsed lasers on dense gases is the pumping from the generators with inductive energy storages.[5] At present, inductive energy storages are used more widely for pumping pulsed gas lasers of various types.[6–10] The advent and advances in the SOS-diodes[11] is the most important factor determining the success in the developments of that kind. Such semiconductor devices have high reliability and can work at high pulse repetition frequencies. As shown in Ref. 12 at decrease in the current cut-off amplitude, SOS-diode can work at the pulse repetition frequency of 12 kHz, and at low electric currents it can be operated at frequencies up to 100 kHz (see Ref. 13).

For obtaining the lasing in nitrogen, pumping by both transverse[1–4] and longitudinal discharge[14–17] is possible. The lasers pumped using longitudinal discharge work at high repetition frequencies without working gas circulation, but have restrictions on the length of laser tube. Thus, as shown yet in Refs. 14 and 15 the UV-lasing power in nitrogen laser rapidly falls off as the length of the discharge tube exceeds 30 cm.

The aim of this study was to find a way of increasing the active length of the discharge tube of the nitrogen UV laser excited by longitudinal discharge, without a decrease in the lasing power. To solve this problem, we have used the generator with the inductive energy storage and took into account the results of investigations into the discharge formation in non-uniform electric field.[18–20]

1. Experimental setup and techniques

For investigations, we have used a setup similar to that described in Ref. 17. It consists of a pulse generator and a laser tube. Pumping was carried out from an inductive energy storage; the electric circuit is shown in Fig. 1.

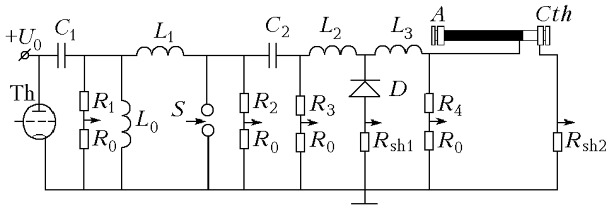

Fig. 1. The electrical schematic of pump generator of nitrogen laser with the inductive energy storage based on a semiconductor current switch: $+U_0$ is the charging voltage of positive polarity; Th is the TGI-1000/25 thyratron; C_1 is the primary capacitive energy storage; C_2 is the secondary energy storage; L_0 is the charging inductance; L_1 is the linear inductance of 6.8 μH; L_2 is the inductive energy storage; L_3 is the inductance of electric conductors; S is the discharge switch of a trigatron type; D is the SOS-diode; $R_0 - R_4$, R_{sh} are the resistance voltage dividers and the resistance shunt; A and Cth are the anode and cathode of the gas-discharge laser chamber.

Ignition of the discharge switch of a trigatron type was performed by applying the high-voltage pulse at the moment of the maximum voltage at C_1 (5.5 nF capacitance). The capacitors C_1 and C_2 have been assembled of ceramic capacitors KVI-3 (10 kV, 3300 pF) connected in series and in parallel. As a current switch D, special SOS-diodes[5] were used. Their maximum reverse voltage can reach 120 kV and the maximum amplitude of the cut-off current of 4.0 kA.

The discharge was excited in the ceramic tubes with the inner diameter of 0.7 and 0.9 cm, the lengths of which were 19 and 49 cm. Design of the laser tube with electrodes and mirrors is shown in Fig. 2.

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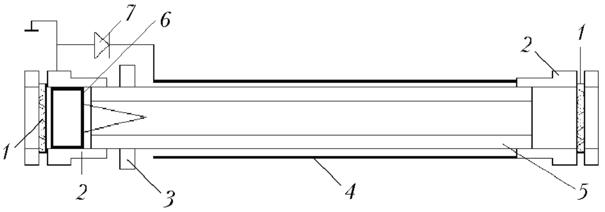

Fig. 2. Schematic presentation of the laser chamber: *1* are the mirrors of the laser cavity; *2* are the brass electrodes; *3* is the insulator; *4* is the copper braiding; *5* is the ceramic tube; *6* is the copper ring with the Y-shaped cathode; *7* is the SOS-diode.

The outer surface of the tube is shielded from the side of potential electrode with a metal screen. A gap between the screen and the grounded housing was equal to 75 mm, and the ceramic tube has been deepened into the housing at 15 mm. For stabilization of the discharge breakdown an Y-shaped electrode was inserted into the tube. This electrode point was directed to the anode and connected to the cathode whose length from the ceramic tube edge varied from 2 up to 130 mm. The experiments also were carried out without the Y-shaped electrode. The pulse repetition frequency usually was 10 Hz. The laser has also been operated at the pulse repetition frequencies of 8, 30, 50, and 100 Hz.

The resonator was formed by an Al-coated plane mirror and a plane-parallel quartz plate. Energy and the average radiation power were measured with an IMO-2N calorimeter, the shape of the emission pulse was recorded with a FEC-22 SPU photodiode. The oscillograms of voltage and current were recorded with a resistance voltage dividers and current shunts or Rogowski coils. A high-speed TDS3032 digital oscilloscope recorded electric signals.

2. Experimental results

In Refs. 14 and 15 devoted to the study of nitrogen laser pumped by longitudinal discharge, as we already noted, fast reduction of pulse and average radiation power was observed at the increase of the laser tube length above 30 cm. The tests of two tubes of 19 and 49 cm lengths yielded similar results. Pulse energy achieved in a tube with 19-cm length was ~ 0.2 mJ under optimum conditions and the laser stably operated in the pulse-periodic mode at the repetition frequency up to 100 Hz. The optimum nitrogen pressure was about 21 Torr.

The lasing observed in a laser with a 49-cm long tube was very unstable and had small pulse energy even in the best pulses. It is worthy to note that for pumping both of the tubes we used the generator with the inductive energy storage. It allowed us to maintain the amplitude of voltage pulse applied to the gap at more than 100 kV level. The representative oscillograms of current running through the SOS-diode and voltage pulse applied to the laser chamber are shown in Fig. 3.

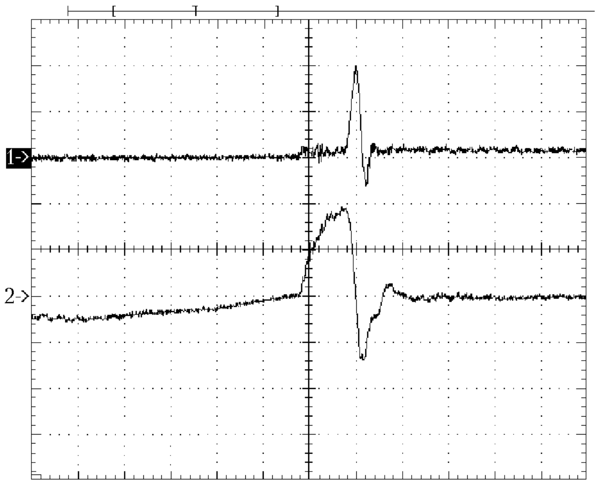

Fig. 3. Oscillograms of voltage pulses (1) on the anode of a laser head (vertical scale 65 kV/div) and current (2), running through the SOS-diode and shunt R_{sh1} (vertical scale 620 A/div) under no-load conditions. The horizontal scale is 50 ns/div.

It is seen, that the cut-off current of the SOS-diode makes about 1.2 kA, and voltage on the discharge gap reaches about 130 kV. The principal cause of lasing instability and small radiation energy per pulse are the lag times of the gas breakdown in a long laser tube at pressures corresponding to the optimum values of E_0/p parameter (E_0 is the electric field strength at the gap breakdown, p is the nitrogen pressure). A stable breakdown of a laser tube could be maintained only at nitrogen pressures appreciably below the optimum. The introduction of an Y-shaped electrode connected to the cathode inside the ceramic tube, has allowed solving this problem. Since the Y-shaped electrode has been made of wire of a small diameter (0.3 mm) and was assembled one side of the laser tube, it practically did not influence the distribution of radiation power in the output beam. Note that the output beam cross section usually had a ring shape.

Figure 4 presents the dependence of the average radiation power obtained in the experiments with the Y-shaped electrode on its length d from the ceramic tube edge.

It is seen from this dependence that there are two optima providing approximately identical average radiation power. Figure 5 shows dependences of the average radiation power of the laser on the nitrogen pressure.

Use of the Y-shaped electrode has allowed us to essentially extend the range of working pressures in this laser (up to 50 Torr). Moreover, at increasing d, we observed an increase in optimum pressure (Fig. 5).

Figure 6 illustrates the influence of pressure and location of the Y-shaped electrode on the shape of the lasing pulse.

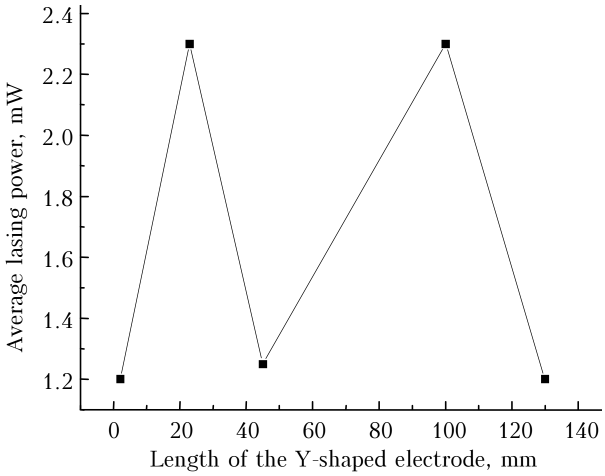

Fig. 4. Dependence of the average radiation power of the nitrogen laser pumped by longitudinal discharge on the length of the Y-shaped cathode. Pulse-periodic mode at the pulse repetition frequency of 10 Hz.

At optimum and lower pressures, a single-peak shape of radiation pulse is observed that is typical of the nitrogen laser with a short laser tube. At the increased pressures two peaks are usually observed, the amplitude and location of which depend on the nitrogen pressure and the length of the Y-shaped electrode.

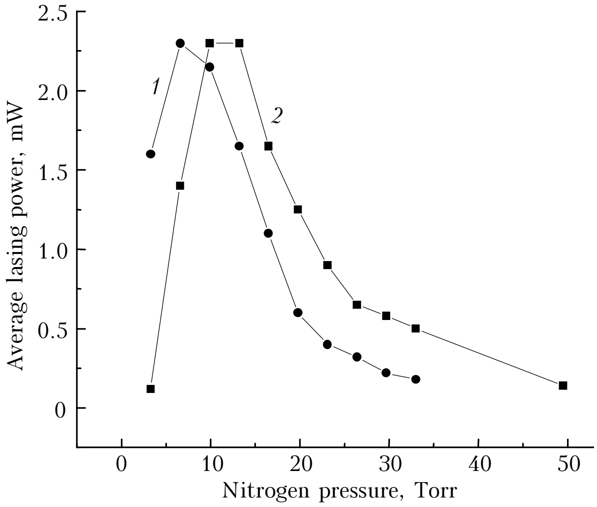

Fig. 5. Dependences of the average radiation power of the nitrogen laser pumped by longitudinal discharge on the active medium pressure for two Y-shaped cathodes of various length: d equal to 23 mm (*1*); to 100 mm (*2*). Pulse-periodic mode at the pulse repetition frequency of 10 Hz.

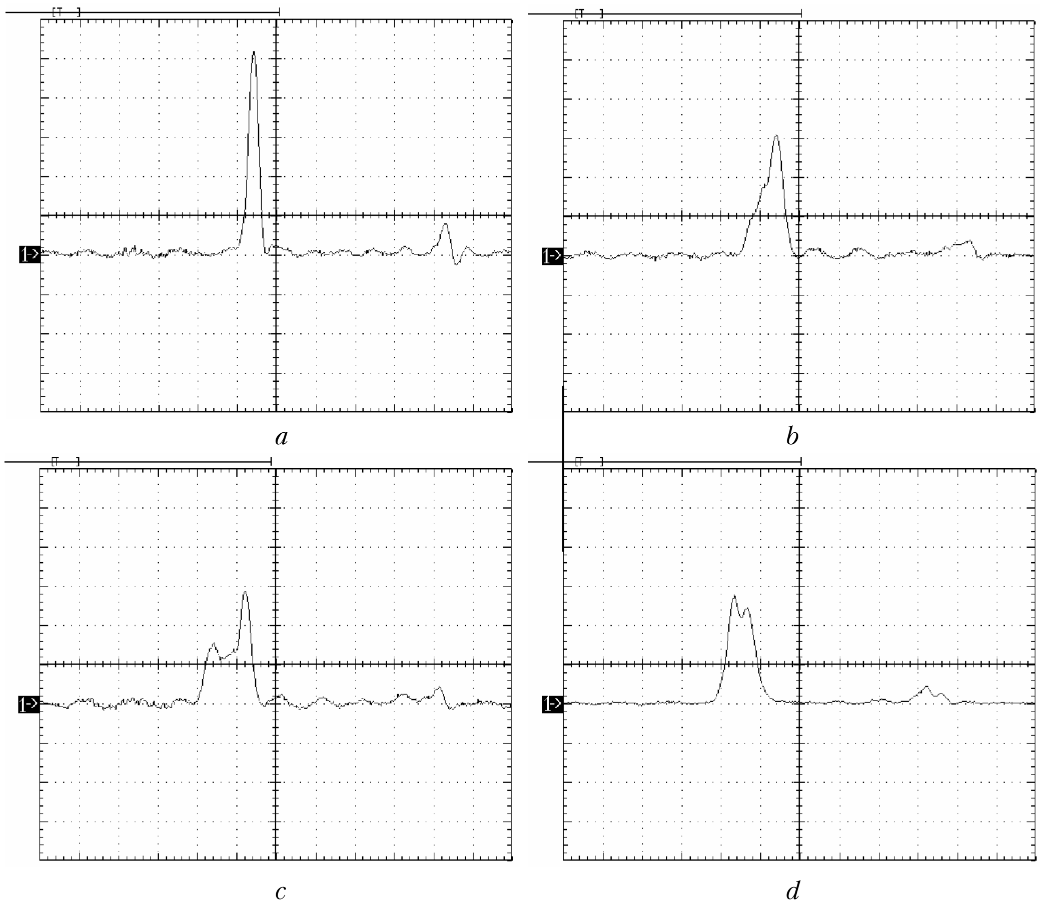

Fig. 6. Oscillograms of the laser pulses of nitrogen laser. Length of the Y-shaped cathode is 100 mm. Pressure in the laser cell: 6.6 (*a*); 11.6 (*b*); 18 (*c*); 49.5 Torr (*d*). The vertical scale: 32 V/div (*a* and *b*) 16 V/div (*c*); 64 V/div (*d*); (*a*)–(*c*) a negative lens was used for signal attenuation; *d* the lens was not used because of the low sensitivity of the recorder. The horizontal scale is 10 ns/div.

3. Discussion of the results

The nitrogen laser refers to the self-contained lasers and demands comparatively high average electron energy, necessary for the effective excitation of the upper lasing level (> 11.7 eV). Therefore, pulse voltage exceeding the static breakdown voltage some times is applied to the discharge gap, thus, the optimum value of E_0/p parameter should make 150–200 V/(cm · Torr) (see Ref. 3). However, in long tubes at low nitrogen pressures corresponding to the optimum values of E/p parameter, the lag time of the discharge gap increases and the breakdown is observed at the voltage pulse droop or at subsequent voltage pulses with the lower amplitude. This leads to unstable operation of the laser, and to the reduction of radiation energy per pulse due to the lower voltage in the gap.

Use of a Y-shaped electrode allows one to increase the electric field strength inside the laser chamber. At small d it takes place due to the electric field growth at the electrode point that, as we assume, leads under these conditions to the emergence of fast electrons[18–20] that preionize a part of the discharge gap. At large d, even stronger field between the point of the Y-shaped electrode and the outer screen surrounding the ceramic tube is attained. As a result, in the beginning, the barrier discharge is formed between the Y-shaped electrode and the inner surface of the tube, being the volume discharge at the increased pressure. The barrier discharge plasma extends toward the potential electrode, stimulating the entire gap breakdown.

The presence of two breakdowns (barrier-restricted one and the complete one) yields two peaks in the lasing pulse (Figs. 6*c* and *d*). Moreover, both at high and low pressure, only single-peak lasing pulse can be observed. At high pressure, the value of E/p parameter at the development of the complete breakdown is small and the lasing threshold is not achieved. At low and optimum pressures the main energy comes to the active medium at optimum value of E/p parameter during the complete gap breakdown. The results obtained confirm the presence of fast electrons in the volume pulse discharges in non-uniform electric field.[18–20]

Conclusion

It is shown that use of a cathode of special shape that enhances the electric field strength inside the laser tube allows one to maintain stable UV-lasing in nitrogen in the discharge gap of a long length (in our experiments it was 49 cm). The obtained results confirm the presence of fast electrons in the volume pulse discharges formed at the non-uniform electric field. Use of the Y-shaped electrode directed toward the anode and connected to the cathode and having the length of 100 mm, enabled reaching the lasing threshold at nitrogen pressure of ~50 Torr and $E_0/p \sim 50$ V/(cm Torr). Thus, the optimum values of E/p parameter were achieved at the breakdown between the point of the Y-shaped electrode and the inner surface of the ceramic tube (in barrier discharge).

Acknowledgments

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