Technical Physics Letters, 2023, Vol. 49, No. 10

04.1;09.2

Nitrogen laser pumped by a pulsed longitudinal electric and inductive discharges

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Received May 23, 2023
Revised August 18, 2023
Accepted August 20, 2023

For the first time, a method for the joint excitation of nitrogen by longitudinal electric and inductive discharges was proposed and experimentally implemented. Laser radiation with wavelengths of $\lambda_1 = 337.1$ nm and $\lambda_2 = 357.7$ nm was obtained. The generation energy reached 0.54 mJ at the pulse duration of 20 ns (FWHM) and nitrogen pressure of $6-7$ Torr with a uniform intensity distribution in the laser beam cross section. Nitrogen pumping by only a longitudinal discharge in the system with similar parameters resulted in decreasing the lasing energy to 0.39 mJ at the nitrogen pressure not higher than 5 Torr and in worsening the laser beam quality.

Keywords: UV nitrogen laser, pulsed inductive discharge, longitudinal electric discharge, lasing energy.

DOI: 10.61011/TPL.2023.10.57057.19635

The nitrogen laser remains at present one of the most popular sources of shortpulse UV radiation [1–3], which finds confirmation in continuous investigation of its active medium and in development of various laser emitter designs and excitation techniques (see, e g. [4–10]). In our studies, we have shown prospects for using the pulsed inductive discharge as an alternative method for pumping the nitrogen laser [11–13]. The inductive discharge gets formed by alternating electromagnetic field in the absence of electrodes in the active medium; this provides a number of advantages, such as high uniformity of the discharge, possibility of using aggressive active media, and long service life of the lasers.

Earlier we have developed several different systems for forming the pulsed inductive discharge; those systems are based on such well-proven circuits as the Blumlein, $C-C$-recharging and *LC*-invertor ones [11–13]. In view of the pumping system operating principle, the inductive discharge is, in essence, a secondary short-circuited plasma coil of the transformer whose primary winding is the inductor. This fact causes significant differences in pumping system performances of the conventional electric-discharge laser and inductive laser. In the latter case, the electric circuit needs the presence of an external high-voltage switchboard. This may be a hydrogen thyratron acting as a single switchboard as, for instance, in the Blumlein and *LC*-invertor circuits; in more complex circuits where recharging of one capacitor to another is performed, an additional untriggered gas-filled spark discharger is typically used jointly with the thyratron. In this case, the discharger plays the role of a circuit breaker, provides the maximal voltage at the sharpening capacitors, and, being actuated, initiates the oscillation process in the primary loop (formation of alternating current in the inductor). Conventional electric-discharge lasers do not need such untriggered dischargers since their function is performed by the inter-electrode spark gap.

For the laser based on molecular nitrogen, stronger requirements are imposed on the rate of energy input into the active medium; therefore, the total amount of the input energy and, hence, capacities in the nitrogen-laser pump circuits, are typically not large. At the same time, the external switchboard is a source of parasitic losses and, in the case of a low total energy resource, its negative effect considerably reduces the total efficiency of the circuit operation (right down to the lasing cutoff). Thus, the goal of this study was to develop a new circuit for pumping the active medium of the inductive nitrogen laser, which involves a longitudinal electric discharge instead of the untriggered discharger and, thus, makes possible the joint nitrogen pumping with the pulsed longitudinal electric and inductive discharges.

Fig. 1 presents the electrical circuit diagram for the joint pump system whose operating principle is similar to that described in [12]. In the experiments there was used an inductive laser emitter made from glass and consisting of a capillary 8 mm in the inner diameter and bypass channel 20 mm in diameter. On the emitter there was wound an antenna inductor [13] made from the PV-3 wire 1.5 mm^2 in cross section. The laser optical cavity was formed by the rear planar aluminum mirror and the output one (KU-1 quartz plate) mounted on metal adjustment assemblies. To realize the nitrogen pumping with the longitudinal electric discharge, this emitter was integrated into the electrical circuit in parallel to capacitors C_2 and C_3. In this case, the longitudinal electric discharge was ignited between the adjustment assemblies playing the roles of hollow cathode and anode, and, thuswise, spark gap SG 415 mm long was formed. The length of the inductive spark gap was

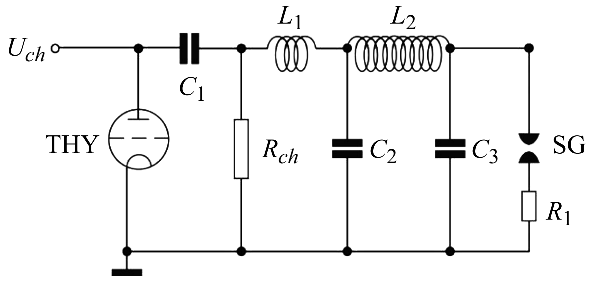

Figure 1. Electrical circuit diagram for joint nitrogen pumping with the longitudinal inductive-electric discharge. THY is the TPI1-10k/20 thyratron, R_{ch} is the charging resistor, L_1 is the pumping system bar inductance, $C_1 = 30{-}40\,\text{nF}$, $C_2 = C_3 = 3.9\,\text{nF}$, L_2 is the inductor, SG is the spark gap, R_I is the current shunt.

about 300 mm. The charging voltage in our experiments was 24 kV. As the active medium, pure nitrogen was used. The pulse repetition rate was 1 Hz.

In the mode of nitrogen pumping jointly with the longitudinal electric and inductive discharges, lasing was obtained at the 0–0 ($\lambda_1 = 337.1\,\text{nm}$) and 0–1 ($\lambda_2 = 357.7\,\text{nm}$) transitions of the 2^+ molecular nitrogen band system (the 0–1 band emission intensity was about 100 times lower). The maximum lasing energy at those wavelengths equaled 0.54 mJ and was achieved at the nitrogen pressure of approximately 6–7 Torr. The efficiency factors from the accumulated and input energy were 0.00625 and 0.15%, respectively. This is lower than in the case of optimized electric-discharge nitrogen lasers pumped with the longitudinal discharge [14]; however, the laser design is currently non-optimized, and, thus, the efficiency also is not maximum achievable and will be raised in further experiments. The lasing pulses were bell-shaped, and their FWHM duration was about 20 ns (Fig. 2, *a*). After that, the inductor was removed from the tube, and the laser emitter was pumped only by the longitudinal electric discharge. In this configuration there were used the same values and mutual arrangements of the C_2 and C_3 capacities in the circuit, as well as the same charging voltage 24 kV; the procedures of the performed nitrogen pumping experiments were also the same. Under those pumping conditions, the lasing energy became considerably lower (down to 0.39 mJ) with a concurrent optimal pressure decrease to 5 Torr. Duration and shape of the lasing pulses remained virtually unchanged (Fig. 2, *b*).

In addition, the laser beam profiles were studied depending on the configuration for both the joint pumping and pumping with the longitudinal discharge only (Fig. 3). In the case of joint pumping, the intensity distribution over the beam cross-section was almost absolutely uniform, while in the case of pumping with only the longitudinal discharge the laser spot had an irregular shape and nonuniform intensity distribution.

To study characteristics of the nitrogen laser with joint pumping in more details, we are going to carry out more investigations. Based on already obtained experimental data, we can assume the following. Figs. 2, *a* and *b* present oscillograms of voltages at the C_2 and C_3 capacitors, current I of the longitudinal electric discharge detected with the current shunt, and lasing optical pulse W for the cases of joint pumping and pumping with the electric discharge only. One can see that in both cases the lasing begins at the front edge of the electric discharge current I; the time delay between the onsets of discharge current and lasing is considerably shorter in the case of joint pumping. Along with this, the capacitor C_3 voltage at the stage of charging is somewhat delayed relative to U_{C_2}, which results in arising of voltage U_L at the inductor even prior to the moment of the spark gap breakdown. We assume that, due to this, the pulsed inductive longitudinal discharge begins to form, which results in ignition of the pulsed inductive discharge acting as pre-ionization with respect to the longitudinal electric discharge. This allows increasing the nitrogen operating pressure and, hence, enhancing the lasing energy; in addition, the beam quality may be improved. To assess the effect of current of the inductive discharge itself on the nitrogen pumping, it is necessary to perform special-purpose experimental and theoretical studies; this is just the objective of our further investigations.

Thus, we have demonstrated the advantage of nitrogen pumping jointly with the pulsed longitudinal electric and inductive discharges. This scheme of pumping ensures high

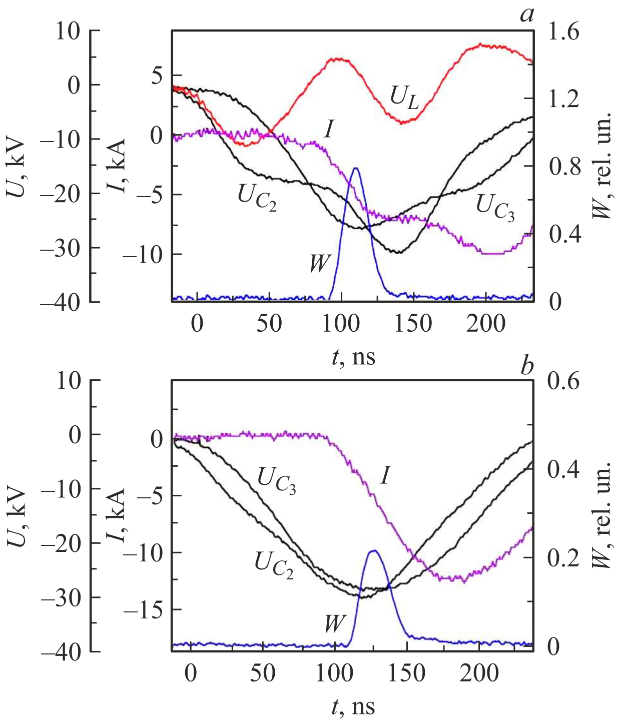

Figure 2. Pulses of voltage U at capacitors C_2 and C_3, voltage U_L at inductor U_L, discharge current I, and lasing optical pulse W. *a* — in the case of joint pumping with the longitudinal inductive and electric discharges; *b* in the case of pumping with the longitudinal electric discharge.

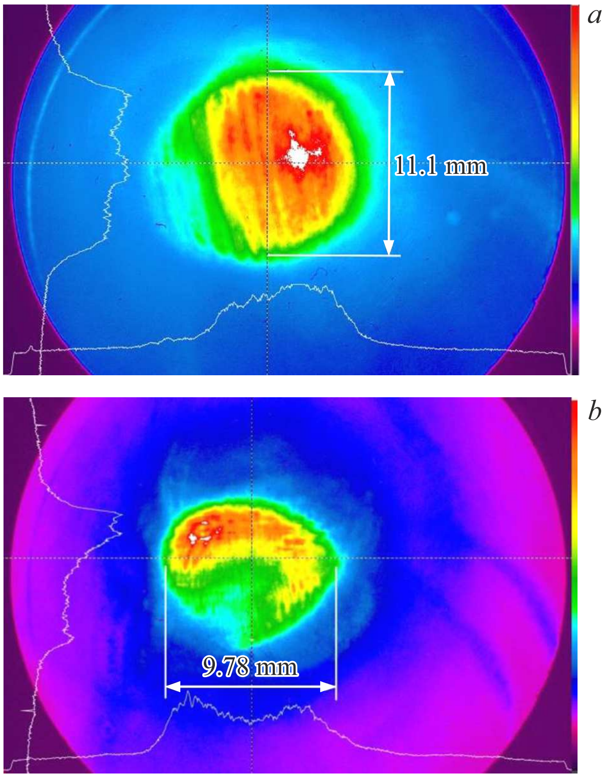

Figure 3. Profile of the lasing beam cross-section for the nitrogen laser. *a* — in the case of joint pumping with the longitudinal inductive and electric discharges; *b* — in the case of pumping with the longitudinal electric discharge. The strips in the beam images appear due to the interference on the surfaces of laser cavity optical elements.

uniformity of the discharge and good quality of the laser beam at larger discharge tube diameters and, hence, the possibility of creating efficient nitrogen lasers for various practical applications.

Financial support

The study was supported by the Russian Scientific Foundation (project № 23-22-00116).

Conflict of interests

The authors declare that they have no conflict of interests.

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Translated by Solonitsyna Anna