PULSED LASERS PUMPED WITH THE LONGITUDINAL DISCHARGE USING INDUCTIVE ENERGY STORAGE

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Experimental investigation of a nitrogen laser pumped with the longitudinal discharge using a generator with an intermediate inductive energy storage, magnetic and semiconductor switches is presented. It was shown that the use of peaking capacitors decreases energy losses in the opening switch and increases the output laser energy by a factor of two. Pulse power of laser radiation up to 40 kW *and the average one of* 12 mW, *respectively, were demonstrated. Pulse-repetitive mode of the laser operation at a pulse repetition rate up to* 100 Hz *was also demonstrated. It is assumed that the use of inductive energy storage provides a possibility to improve the efficiency of capillary lasers generating pulses of soft X-ray radiation.*

Inductive energy storage was first applied to pumping gas lasers on dense gases in 1975 (see Ref. 1). Generators with an inductive energy storage can easily vary pumping modes and provide optimal excitation of lasers of different types (see Refs. 2–7). Nevertheless, the absence of simple and reliable opening switch providing cutoff of current with the amplitude up to hundreds of kA and generating voltage pulses up to hundreds of kV had limited this pumping technique. The use of industrial semiconductor diodes of SDL type which under certain conditions have the property of cutting off the current of the opposite direction and the development of special semiconductor opening switches (SOS) (see Refs. 8 and 9) significantly improve the possibilities of applying generators with the inductive energy storage (IES) (see Refs. 4, 5, 7, and 8). For instance, Ref. 7 reports on the development of non-chain HF-laser with the output energy of 0.5 J and efficiency of 3%. The results of investigation of N_2 lasers pumped with a generator with IES and semiconductor opening switch using the simplest one-circuit scheme are presented in Refs. 4 and 5.

In this paper we present the development of pumping generator including intermediate inductive energy storage, specially designed semiconductor opening switch (see Ref. 9), and a commutator based on the saturating magnetic switch. The generator was used for pulse-repetitive longitudinal discharge excitation of a nitrogen laser.

The circuitry of the generator is shown in Fig. 1. Storage capacitor C_1 = 2.8 nF was charged through the inductor L_2 = 1.3 μH and the opening diode D to the voltage U_0 = −32 kV during t ~ 400 ns from a primary thyratron generator. Special silicon diode of SOS-100-2 type with the maximum inverse voltage of 100 kV and the amplitude of the opening current of 2 kA

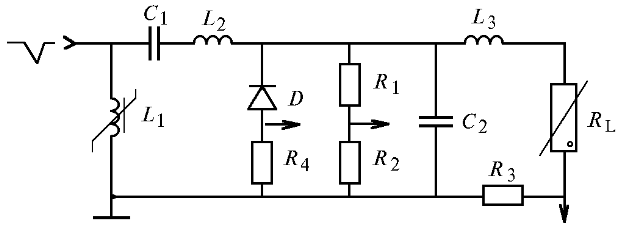

FIG. 1. Circuitry of the experimental setup. C_1 and C_2 are the storage and peaking capacitors, respectively; L_1 is the magnetic switch; D is the semiconductor opening switch; L_2, L_3 are inductors; R_1 is the load resistance; R_1–R_4 are resistive voltage divider and shunts.

(see Ref. 9) was used as the opening diode. The voltage across the C_1 reverses magnetization of the magnetic switch L_1 consisting of non-linear throttle built on a core 6 cm^2 in cross-section and 10 cm in average diameter made from 50NP Permalloy band with the thickness of 0.01 mm. The number of turns was 4. By the time C_1 is fully charged the core saturates and C_1 begins to discharge through the circuit C_1–L_1–D–L_2. Therewith the diode current has inverse polarity. Rise time of the current in this circuit is ~80 ns. By the time the current reaches its peak the charge stored in the diode dissipates and the current is cutoff in a time of ~10–20 ns. At the expense of the energy stored in the inductor (L_1 = L_2 saturated) the voltage pulse appears across the load R_L and diode D charging peaking capacitor C_2 connected in parallel to the diode to a voltage of ~80 kV in a time of 20–50 ns depending on C_2 value. The breakdown voltage of the laser tube was

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observed at voltage across C_2 of ~50 kV. Therewith the discharge current was a sum of current through the inductive energy storage and peaking capacitor C_2. Input inductance was made as small as possible. Quartz tube 20 cm long and 6 mm of the inner diameter filled with nitrogen and connected with minimum inductance in parallel to the diode was used as a load. The internal optical cavity consisting of plane aluminized mirror and a quartz plate was mounted on the ends of the tube. As was mentioned above, in the majority of experiments the peaking capacitor was connected in parallel to the tube. Its value varied from 10 to 940 pF. The voltage across the tube, diode and the discharge current were measured using a resistive voltage divider R_1–R_2 and shunts R_3 and R_4, respectively. The signals were recorded with an oscilloscope S7 – 10B. The laser pulse waveform and output energy were recorded using a FEK – 22SPU photodiode and a calorimeter IMO – 2N, respectively.

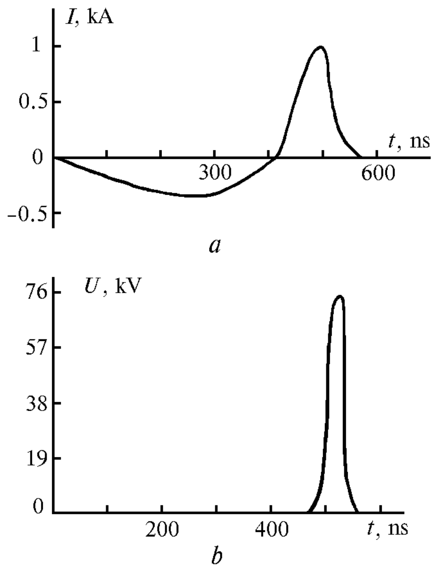

FIG. 2. Oscillograms of the current through the semiconductor opening switch (a) and voltage across the tube without a load (b).

Figure 2 depicts oscillograms of the diode current and voltage across the tube obtained without a load. The peak direct diode current was as high as 350 A. Amplitude of the inverse current just before its cutoff reaches 1 kA, the diode opening time in the optimal regime does not exceed 20 ns. At the instant of current cutoff the voltage pulse with the amplitude up to $U \approx 3U_0$ and about 40 ns in duration was formed across the tube. Typical rise time of the pulse was of the order of 20–30 ns and can be reduced to 10 ns when several diodes operate in parallel. When cooling the diode and tube in oil and air the generator can operate at a pulse repetition rate up to 100 Hz.

Oscillograms of the voltage and discharge current when the generator pumps the tube are shown in Fig. 3. The gas breakdown was observed at the voltage of about 50 kV while the discharge current reaches 80% of that through the inductive storage. The use of peaking capacitor decreases a little bit the rise-time of the voltage pulse and increases the discharge current amplitude thus increasing the laser emission power. Note that due to a short rise-time of the voltage pulse across the tube the gas breakdown in the regime without peaking capacitor was observed at higher voltage than that with the capacitors. Therefore, the majority of our experiments were made with the capacitor. Its optimal value was found to be 170 pF. In this case the discharge current increased by a factor of two while the radiation power at λ = 337 nm and pulse energy were as high as 40 kW and 0.2 mJ, respectively. Nitrogen pressure corresponding to the peak radiation power was 12 Torr. As C_2 was further increased the output energy fell down and at C_2 = 900 pF it reached minus one order of magnitude. It should be pointed out that the presence of peaking capacitor and its value produce the effect on the energy losses in the opening switch which define the operation efficiency of the generator. Figure 4 depicts the energy dissipated in the opening diode during the current cutoff at no-load versus C_2 value. It is seen that the losses increase with increasing voltage across the load and decrease as C_2 increases. When C_2 = 220 pF the losses do not exceed 25% of the energy stored in C_1.

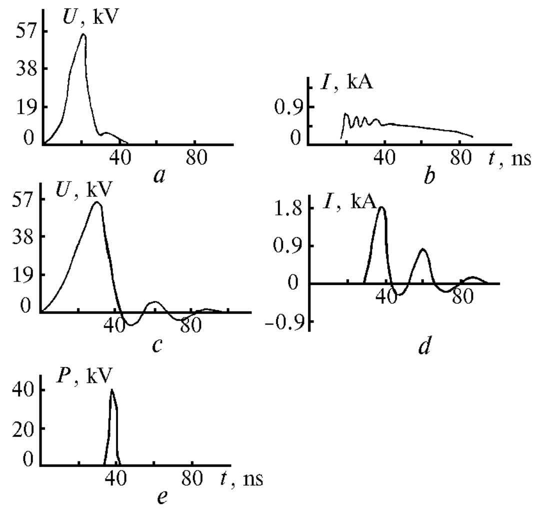

FIG. 3. Oscillograms of the voltage across the tube (a,c), discharge current (b,d) and laser radiation (e). The generator operates on the tube. C_2 = 0 (a,b) and 170 pF (c,d,e).

The mean power of the emission was measured at the pulse repetition rates (PRR) of 10 to 100 Hz and reached 12 mW at 100 Hz. The maximum energy per pulse has been recorded at the PRR of 20 to 50 Hz. The fall off of the pulse energy at PRR > 50 Hz is most likely due to the gas over heating because the gas discharge tube diameter was too large. Use of oil for cooling the diode and laser tubes of smaller diameter may provide for an essential increase of both the pulse repetition rate and the mean output power of the laser emission.

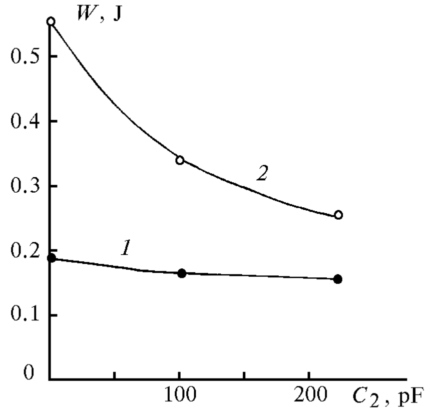

FIG. 4. The energy dissipated in the diode during the current cutoff at no-load versus C_2 value. Voltage across the load is lower than 50 *(1) and* 70 kV *(2).*

In conclusion we should like to note that generators with the inductive energy storage provide excitation with the single-polarity pulses with short rise-time and efficient energy transfer to the load. In this connection an improvement in the efficiency and output energy of the capillary lasers emitting pulses of soft X-rays can be expected if pumped with such generators. Therewith at present semiconductor diodes (see Refs. 4, 5, 8, and 9) and plasma erosion opening switches (see Refs. 2, 3, and 5) are most promising.

REFERENCES

1. Yu.I. Bychkov, V.F. Losev, Yu.A. Kotov, and V.F. Tarasenko, Kvant. Elektron. **3**, No. 7, 1607–1608 (1976).
2. G.A. Mesyats, A.N. Panchenko, and V.F. Tarasenko, Dokl. Akad. Nauk SSSR **307**, No. 4, 869–872 (1989).
3. A.N. Panchenko and V.F. Tarasenko, Kvant. Elektron. **17**, No. 1, 32–34 (1990).
4. M.I. Lomaev and V.F. Tarasenko, *ibid*. **22**, No. 2, 441–442 (1995).
5. M.I. Lomaev, A.N. Panchenko, and V.F. Tarasenko, Atmos. Oceanic Opt. **8**, No. 11, 883–888 (1995).
6. V.D. Bochkov, N.M. Vereshchagin, F.G. Goryunov, et al. *ibid*. **9**, No. 2, 146–150 (1996).
7. M.I. Lomaev, A.N. Panchenko, and V.F. Tarasenko, Kvant. Elektron. **24**, No. 6, 511–512 (1997).
8. Yu.A. Kotov, G.A. Mesyats, S.N. Rukin, and A.L. Filatov, Dokl. Akad. Nauk SSSR **330**, No. 3, 315–317 (1993).
9. G.A. Mesyats, S.N. Rukin, S.K. Lyibutin, et al., in: *Proc. 10th IEEE Pulse Power Conf.* (Albuquerue, USA, 1995), pp. 289–305.
10. J.J. Rossa, in: *Proc. of AIP Conf.* **332**, (USA, 1994) pp. 359–361.