PECULIARITIES OF PUMPING A SF_6-H_2 (C_3H_8) LASER MIXTURES USING GENERATOR WITH AN INDUCTIVE ENERGY STORAGE

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Received June 2, 1997

The results of investigation of non-chain HF *laser pumped with an inductive energy storage generator and semiconductor opening switch are presented. The peculiarities of operation of the generator of this type on gas-discharge load are shown using active media of non-chain* HF *laser as an example. Output energy of* 0.6 J*, the lasing efficiency relative to the deposited energy of* 5.5% *and total efficiency (relative to energy stored in the capacitor) of* 3.5% *were demonstrated. The possibility of scaling the laser output up to* 1 kJ *is discussed.*

In recent years interest in discharge HF(DF) lasers pumped with non-chain chemical reaction has considerably increased (see Refs. 1–4). These lasers are usually pumped with capacitive generators of different design. Therewith the discharge contraction, as a rule, limits the efficiency of HF (DF) lasers to < 3%. Therefore the volume discharge formation in mixtures of hydrogen or deuterium donors with SF_6 is of great importance for improving the parameters of HF lasers. A considerable body of works has been devoted to this problem. For instance, significant improvement of the discharge stability in Ar-SF_6 mixture under intense preionization by *e*-beam was noted in Ref. 6. For the discharge contraction to be suppressed the authors of Ref. 7 proposed to cover electrodes with a dielectric material. Improvement in the discharge stability in gas mixtures of chemical laser was observed in Ref. 3 when molecules C_nH_{2n+1} ($n > 3$) were used instead of hydrogen that simplified the requirements for intensity and uniformity of the preionization. In Ref. 4 it was shown that application of a generator with an inductive energy storage and semiconductor opening switch for pumping HF laser makes the volume discharge formation in gas mixtures containing SF_6 much more easier and improved the non-chain chemical laser efficiency.

The present paper being a continuation of Ref. 4 considers peculiarities of HF laser pumping with an inductive energy storage generator and analyzes different regimes of its operation.

The laser schematic is shown in Fig. 1. Cylindrical discharge chamber with the active volume of 1×3.3×55 cm^3 (discharge gap is d = 3.3 cm) made from a dielectric material is similar in design to that described in Ref. 8. The emission from a barrier discharge passed through a perforated anode was used as the preionization source. The preionization intensity was determined by the capacitance C_2. Fourteen semiconductor diodes of SDL–0.4–800 type connected

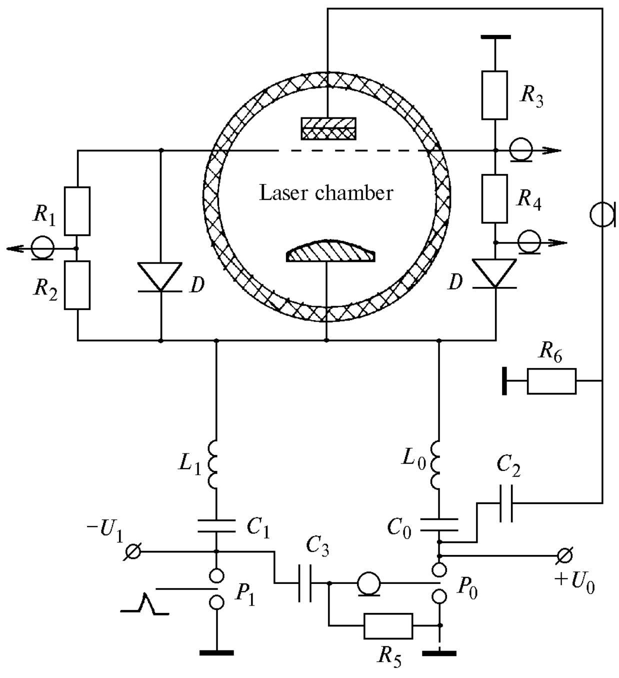

FIG. 1. Schematic of the laser pumped with an inductive energy storage generator. D are the semiconductor diodes; P_0, P_1 are RU–65 *spark gaps; C_0, C_1 are capacitors of the main and driving circuits, respectively; C_2 is the preionization capacitor; C_3 is the triggering capacitor P_0; L_0, L_1 are the circuit inductors; R_1 – R_6 are the resistive shunts, voltage divider and charging resistors, respectively.*

in parallel with the gap were mounted inside the chamber. Capacitors C_1, C_0 and their charging voltages U_1, U_2 in the circuit of preliminary current passage through the diodes (driving circuit) and the main circuit were as follows: C_1 = 12–25 nF, C_0 = 45 nF,

U_1 = 25 kV, U_0 = 15–30 kV. The time of preliminary current passage being equal to the half-period of the current oscillations in the driving circuit was chosen to be 800 ns, while the current in that circuit was one order of magnitude lower than that in the main one. Currents in the circuits, voltage across the gap and laser radiation pulses were measured using resistive shunts, voltage divider, photodetector FSG–0.22, and an oscilloscope S8–14. The laser pulse energy was measured with a calorimeter IKT–1N. Working mixtures composed from SF_6 and hydrogen or propane were prepared directly in the chamber. The laser cavity was formed by a copper mirror with the radius of curvature of 5 m and plane-parallel KRS–5 plate.

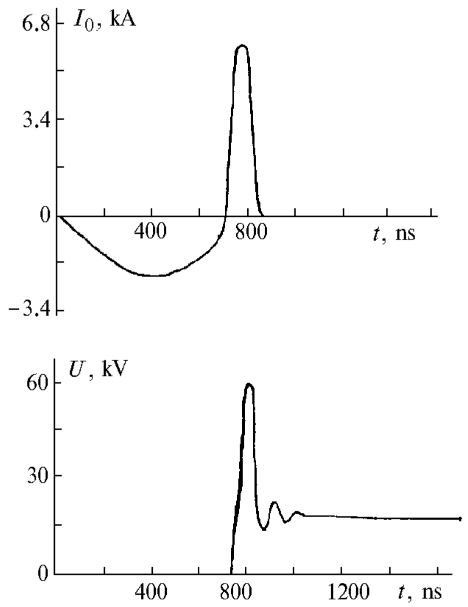

FIG. 2. Oscillograms of the current through the opening switch (a) and voltage across the chamber electrodes (b) under no-load operation. C_0 = 45 nF, U_0 = 19 kV.

In Fig. 2 are shown the oscillograms of the current and voltage across the semiconductor opening switch under no-load operation. In our experiments the opening switch has opening current up to 7 kA (opening current per diode I_d ~ 500 A). Therewith about 70% energy accumulated in the capacitor C_0 was transferred into the inductive storage. The cutoff time does not exceed 40 ns (dI/dt ~ 100 A/ns). The generator forms voltage pulses across the laser gap with the amplitude exceeding by a factor more than two the charging voltage at C_0 and rise up to 2 kV/ns.

The oscillograms of the voltage across the gap, discharge current and laser radiation are presented in Fig. 3. Pumping pulse duration does not change, while its duration (FWHM) increases from 75 to 110 ns as U_0 increases. Once the breakdown of the gap occurred the quasi-stationary discharge phase with E/p = 120 V/cm·Torr, where $E = U/d$ is the electric field strength, is observed. The laser oscillation begins 40 ns after the breakdown and lasts about 500 ns. The pulse radiation power exceeds 1 MW. Note that similar to Ref. 9 the laser pulse duration increases as the hydrogen content in gas mixture decreases.

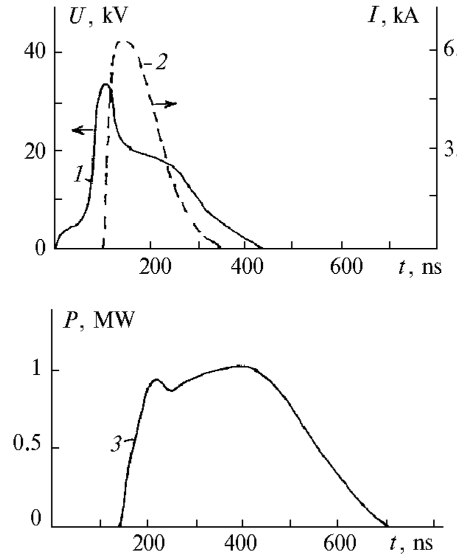

FIG. 3. Oscillograms of thE voltagE across thE chambEr ElEctrodEs (1), chambEr dischargE currEnt (2) and HF *lasEr radiation pulsE (3) obtainEd in* $SF_6:C_3H_8$ = 20:1 *gas mixturE at* p = 45 Torr *and* U_0 = 25 kV.

Figure 4 presents emission pulse energy and HF laser efficiency versus charging voltage obtained at different preionization intensities. When C_2 = 3.5 nF (C_2 value at constant U_0 controls the preionization intensity) the laser energy in propane containing mixtures is higher than that in hydrogen ones and ranges up to 0.5 J. As the intensity increases (C_2 = 5.5 nF) the laser energy increases up to 0.6 J, other conditions being the same. Besides, when the preionization conditions are improved it has been possible to greatly extend the volume discharge lifetime which in some experiments is found to be more than 1 μs due to the discharge of the driving circuit capacitor C_1. At C_2 = 5.5 nF the laser energy obtained in SF_6–H_2 and SF_6–C_3H_8 gas mixtures differs by no more than 10%.

The peak total efficiency of the laser (relative to the energy stored in the capacitors) was as high as 3.5% that well exceeds that obtained in Ref. 6 using X-ray preionization and a pumping generator with the capacitor energy storage. The improvement of the total efficiency and equally high efficiency obtained in SF_6–H_2 and SF_6–C_2H_8 gas mixtures are caused by uniform discharge formation provided by the inductive energy storage at an intense preionization.

Based on the above data let us consider the peculiarities of the inductive generator performance on

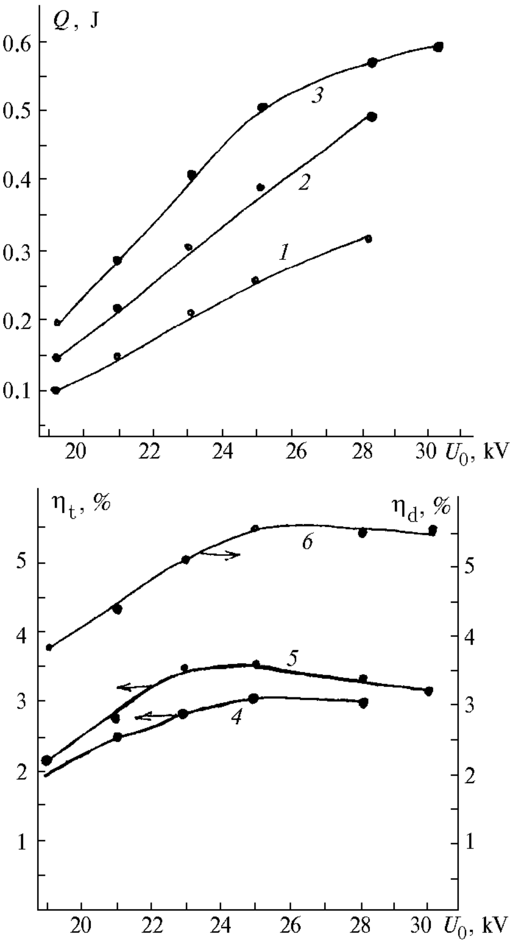

FIG. 4. Laser energy Q (a), total laser efficiency η_t *and relative to the deposited energy* η_d *(b) versus charging voltage of the main capacitor storage* C_0. $C_2 = 3.5$ nF *(1, 2, 4) and* $C_2 = 5.5$ nF *(3, 5, 6). Mixture pressure* $p = 45$ Torr; *curves 1 and 2, 3, 4, 5, 6 correspond to mixtures* $SF_6:H_2 = 8:1$ *and* $SF_6:C_3H_8 = 20:1$, *respectively.*

a gas-discharge load. When using an inductive storage the rate of voltage rise (and the overvoltage across the laser gap at its breakdown) was found to be determined by the opening time of the opening switch and it exceeded that obtained when the laser was pumped only with the capacitor C_0. As is well known, these parameters have strong effect on the discharge stability in the gas mixtures of SF_6 and H_2 (see Ref. 2). Besides, the generator with the inductive energy storage provides very fast increase of the discharge current, that according to the data presented in Refs. 10 and 11 also improves the discharge stability in gas mixtures containing electronegative gases. Therefore employment of the inductive energy storage highly assists the volume, discharge formation critically important in scaling lasers of this type. In our experiments the volume discharge in SF_6–H_2 mixtures without any evidence of contraction was easy to form at a pressure over 100 Torr. The generator with the inductive energy storage produces single-polarity pulse of current through the laser gap. Actually, charging current of an inductive energy storage on a resistive load is described by the following expression:

$$I = I_0\ e^{-Lt/R_L},$$

where I_0 is the initial current and R_L is the load resistance. This means that the overall energy accumulated in the inductive storage deposites into the discharge plasma via a single-polarity pulse. In the case of a generator with the capacitive storage matched pumping regime could only be realized using very complicated prepulse schemes (see Ref. 12). In our experiments the laser efficiency relative to the deposited energy ranges up to 5.5% (see Fig. 4*b*). It is easy to see that this efficiency value can be obtained if and only if the energy stored in an inductor is totally transferred to the discharge load. Hence it may be stated that pumping with an inductive energy storage generator can improve the HF laser efficiency.

Pumping pulse duration provided by the inductive generator is equal to $t_1 \sim L_1/R_L$ and depends only slightly on the laser size (in that case L_1 and R_L increase simultaneously). In the case of a capacitive generator $t_c \sim (L_1C_1)^{1/2}$ and increases with the laser size. Hence, employment of the inductive storage can reduce the pumping pulse duration and increase its power (see Ref. 13). Under conditions of our experiment the pumping pulse duration was 200 ns while $t_c \sim (L_1C_1)^{1/2} = 500$ ns and the peak power provided by the inductive generator was doubled.

The inductive generator peculiarities discussed offer great promise to the development of non-chain chemical lasers with high pulse energy. For instance, the pulse energy of 3.2 J at the total efficiency of 16% has been obtained in He–CO_2–N_2 mixtures.

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