

LETTERS

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Energy parameters and stability of the discharge in a nonchain, self-sustained-discharge-pumped HF laser

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***Abstract*. The generation and discharge are studied in a nonchain HF laser operating on mixtures of SF_6 with hydrogen and hydrocarbons. The specific output energy of the laser is 8.8 J L^{-1} (73 J L^{-1} atm^{-1}) and the total lasing efficiency is 5.5 %. It is shown that the formation and maintaining of a volume discharge in self-sustained-discharge-pumped HF lasers with a large content of electronegative gases is caused by the accumulation of the volume discharge of negative ions in conducting regions.**

Keywords: *nonchain HF laser, discharge stability, SF_6, volume discharge.*

The HF and DF lasers pumped by nonchain chemical reactions initiated by a self-sustained discharge attract great recent attention because of their high energy parameters in pulsed and repetitively pulsed regimes [1 – 6]. An important feature of a laser operating on mixtures of hydrogen with SF_6 is the formation of a volume discharge without using a source for additional preionisation, in particular, in the case of large interelectrode distances [7]. However, the mechanisms of formation and maintaining of the volume discharge in mixtures of SF_6 (heavy electronegative gas with a large atomic number) with hydrocarbons and hydrogen in these lasers have not been established, which prevents the development of HF and DF lasers and amplifiers with maximum possible energy parameters.

In this paper, we studied the discharge and generation in a nonchain HF laser, determined the optimal pumping conditions, and obtained the efficiency and specific output energy that are maximal for the laser of this type.

We investigated lasers with active volumes $2.3 \times 1.2 \times$ 62 cm (with the interelectrode distance $d = 2.3$ cm) and $3.3 \times 1 \times 55$ cm ($d = 3.3$ cm). The lasers were pumped by a self-sustained discharge from an inductive [1] and a capacitive energy storage.

The discharge gap was preliminary ionised by radiation from a surface discharge at one of the electrodes (grid electrode). The preionisation intensity could be varied by changing the energy deposited to the surface discharge. In some experiments, no preionisation was used. For comparison, we used a laser pumped by a nonself-sustained discharge initiated by an electron beam in the volume $1 \times 2 \times 42$ cm ($d = 1$ cm). The parameters of the discharge were studied at pressures of SF_6 from 0.03 to 0.2 atm and of SF_6 with hydrocarbons (C_2H_4, C_3H_8) or hydrogen at a large content of the electronegative gas (above 70 %).

The measurements showed that upon preionisation, the breakdown voltage of the discharge gap was usually lower by 10 % – 20 % than in the absence of preionisation. This resulted in a decrease in the amplitude of the current flowing through a laser chamber, but the output energy was increased. In the absence of preionisation, as in papers [3, 5], a discharge first appeared in local regions and then it filled the entire operating area of the electrode. At low initial voltages and low energy inputs, the discharge consists of one or several diffusion channels, which terminate at bright cathode spots. The storage capacitor C_0 discharged incompletely when the charging voltage was decreased or the inductance of the discharge circuit was increased, and the residual voltage across the discharge gap at the value of E/p can amount to 40 kV cm^{-1} atm^{-1} (E is the electric field strength and p is pressure). The presence of a high residual voltage leads usually to a repeated breakdown of the discharge gap, resulting in the formation of a bright channel.

The delay time of the repeated breakdown strongly depends on the preionisation level and the charging voltage U_0, and increases with decreasing U_0. For example, for a laser with the active volume $2.2 \times 1.2 \times 62$ cm, in the case of the maximum preionisation intensity and the charging voltage $U_0 = 30$ kV, the delay time of the repeated breakdown was 750 ns. In the absence of preionisation of the laser gap, this delay is substantially smaller (~ 100 ns) under the same conditions. When the discharge was initiated by an electron beam, no repeated breakdown of the discharge gap was observed even when the initial voltage was close to the static breakdown voltage (the specific energy input was 0.07 kJ cm^{-3}, and the initial voltage decreased by ~ 8 % during the discharge).

To obtain a volume discharge at specific energy inputs of 1 – 2 kJ L^{-1} atm^{-1} that are optimal for efficient lasing and a low residual voltage across the discharge gap, it is necessary to increase the initial voltage across the gap and (or) decrease the inductance of the discharge circuit. In this case, the pump-pulse duration should not exceed 100 – 300 ns. These conditions can be most easily fulfilled upon pumping from an inductive storage and from capacitive storages with the minimum inductance of the discharge circuit. Fig. 1 shows the oscillograms of voltage and current pulses for different gene-

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rators obtained for the same storage capacitor, composition, and pressure of the working mixture. One can see that with the inductive storage, the energy completely transferred from the inductance to the discharge plasma. Upon pumping from the capacitive storage under these conditions, the discharge was contracted after 200 ns and the current increased.

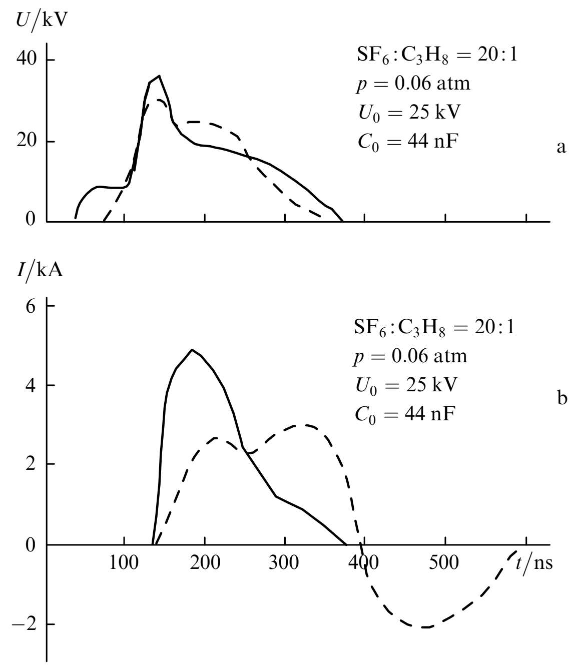

Figure 1. Oscillograms of voltage (a) and current (b) pulses obtained for the same inductance of the discharge circuit upon pumping from the inductive (solid curves) and capacitive (dashed curves) energy storages at the high preionisation intensity.

The characteristics of laser radiation are shown in Figs. 2 and 3. When the preliminary ionisation was used, the output energy and lasing efficiency were high in all the experiments (Fig. 2). This is explained by the fact that the volume discharge is formed not simultaneously over the electrode surface in the absence of preionisation. A comparison of the output energy in mixtures with hydrogen and hydrocarbons showed that at low preionisation intensities or in its absence it is more advantageous to use mixtures with hydrocarbons. However, when the preionisation intensity is increased and the inductive energy storage is used, which allows an increase in the voltage amplitude across the discharge gap and pumping in the matched regime, both mixtures produce the same lasing efficiency and output.

Under optimal conditions, we obtained the lasing efficiency of 5.5 % and the specific output energy of 4.3 J L^{-1} (72 J L^{-1} atm^{-1}) for a laser with an inductive energy storage (Fig. 3). In the case of optimisation of the discharge circuit upon pumping from a capacitive storage and efficient preionisation, the output of the laser with the active volume $2.3 \times 1.2 \times 62$ cm was 8.8 J L^{-1} (73 J L^{-1} atm^{-1}) and its efficiency was 3.3 %.

To build HF and DF lasers with high output parameters, it is very important to understand the mechanism of the formation and maintaining of the volume discharge in mixtures of SF_6 with hydrogen and hydrocarbons at pressures

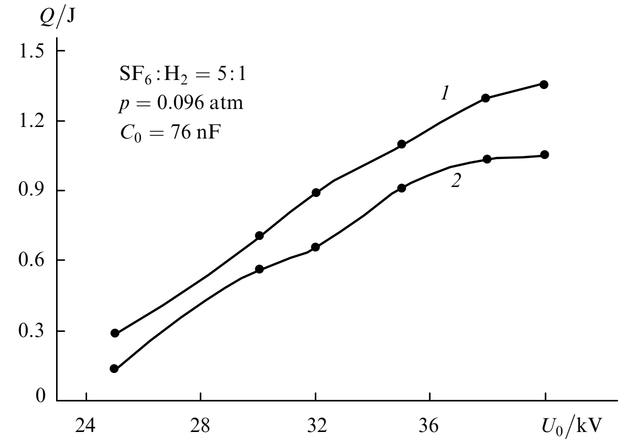

Figure 2. Dependences of the radiation energy on the charging voltage upon pumping from the capacitive storage using preionisation (*1*) and without it (*2*).

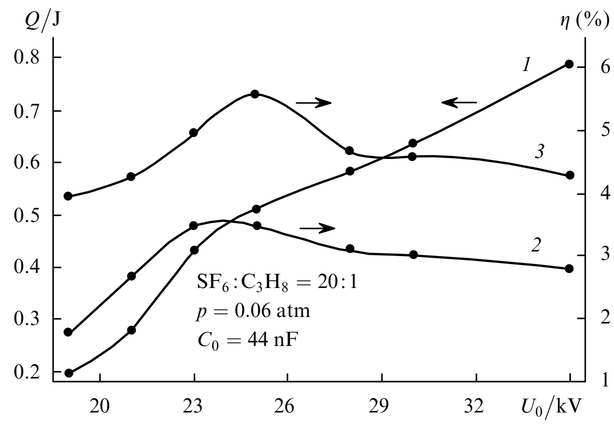

Figure 3. Dependences of the radiation energy of the HF laser (*1*) and its efficiency with respect to the stored (*2*) and supplied (to the inductive storage) (*3*) energy on the charging voltage at the high preionisation intensity.

0.05 – 0.1 atm, in particular, in the absence of preionisation. It follows from the results obtained here and the data from the literature that the volume discharge is formed and maintained due to the production and accumulation of heavy negative ions in the electronegative gas.

The negative charge accumulated in the discharge gap restricts the discharge electron current. The rate of formation of negative ions exceeds the rate of increase in the electron concentration, which restricts the density of the electron current in the regions of its increase and maintains the volume discharge. Theoretical simulations also predict a more rapid increase in the concentration of negative ions compared to the electron concentration [5]. The volume negative discharge prevents the development of a streamer from cathode spots. In the absence of preionisation, the diffusion channel, which is formed in the region of the maximum gain of the field on the cathode, initiates a discharge on the rest of the cathode surface due to preionisation by intrinsic UV radiation.

Note in conclusion that to achieve the maximal energy parameters of HF and DF lasers, it is necessary to use both preionisation and profiled electrodes. This is especially important for the development of lasers and laser systems with diffraction-limited radiation divergence.

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