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Pulsed inductive HF laser*

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Abstract. **We report the results of experimentally investigated dependences of temporal, spectral and spatial characteristics of an inductive HF-laser generation on the pump conditions. Gas mixtures $H_2-F_2(NF_3$ or $SF_6)$ and $He(Ne)-H_2-F_2(NF_3$ or $SF_6)$ were used as active media. The FWHM pulse duration reached 0.42 μs. This value corresponded to a pulsed power of 45 kW. For the first time, the emission spectrum of an inductive HF laser was investigated, which consisted of seven groups of bands with centres around the wavelengths of 2732, 2736, 2739, 2835, 2837, 2893 and 2913 nm. The cross section profile of the laser beam was a ring with a diameter of about 20 mm and width of about 5 mm. Parameters of laser operation in the repetitively pulsed regime were sufficiently stable. The amplitude instability of light pulses was no greater than 5%–6%.**

Keywords: *pulsed cylindrical induction discharge, HF laser, emission spectrum, laser operation stability, ring profile of the beam cross section.*

1. Introduction

Presently, pulsed non-chain HF and DF lasers with initiation of chemical reactions by an electric discharge enjoy certain scientific interest and wide applications [1–12]. Radiation of such lasers is successfully used in various lidar systems for studying atmosphere, finding and measuring the concentration of water vapour and of a number of impurity gases and aerosols [4–8]. For such purposes, HF lasers (more often DF lasers) with the generation energy of 0.5–200 mJ, pulse power of tens to hundreds kW and pulse repetition rate from a fraction Hz to several Hz [4, 5] are usually employed. In addition, in practice, important characteristics of the radiation of HF and DF lasers are the spectral composition and the possibility of fine tuning of the frequency. Also, stable laser operation in the repetitively pulsed regime is needed, i.e. the laser energy should only slightly vary from pulse to pulse.

In [13], for the first time we have demonstrated the possibility of creating chemical lasers initiated by a pulsed inductive discharge. In that work, an inductive HF laser was described, which operated utilising a H_2 – $NF_3(SF_6)$ or He(Ne) – H_2 – $NF_3(SF_6)$ mixture. However, in view of the requirements to laser radiation mentioned above, investigations of spectral, temporal and spatial characteristics of an inductive HF laser as functions of the pump conditions are required, which is the aim of the present work.

2. Experimental setup

In the present work, a pulsed high-voltage system forming an inductive discharge in gases was used, similar to the system described in [13]. This excitation system has a simple design and ensures stable operation of the inductive laser. In our experiments with the repetitively pulsed HF laser operating at a frequency of several Hz, the instability of light pulses was at most 5%–6%.

In experiments, we employed a ceramic discharge tube with an external diameter of 25 mm and length of 800 mm. The inner diameter of the tube was 20 mm. A gas system was used for filling the tube with a gas mixture at the pressure of 0.1–100 Torr. Since the construction of the emitter had no ballast volume, in experiments the waste mixture was renewed by longitudinal pumping at a rate of 0.3–0.5 L min^{-1}. At tube ends, there were adjusting units, which comprised plane-parallel windows made of MgF_2. An optical cavity was formed by plane dielectric mirrors: a rear mirror with the reflection coefficient close to 100% in the spectral range of 2.5–3.5 μm, and an outcoupling mirror with the reflection coefficient varied in the course of experiments. The inductor comprises several separate sections with a stranded PV6-3 wire of a cross-section 10 mm^2 wound on a laser tube and connected in parallel. The total length of the solenoid was 550–600 mm. This value was taken for the laser active length.

Energy characteristics of laser radiation were studied by a PE-50BB pyroelectric energy meter (Ophir Optronics) with a Nova display (Ophir Optronics). Temporal characteristics of generation were measured by using a FD-511-2 semiconductor photodiode with nitrogen cooling and a Tektronix TDS 2024 oscilloscope. The spectral composition of laser radiation was measured by an MDR-204 monochromator with a

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FPU-FS photosensor. The cross-section profile of the laser beam was detected by a Pyrocam digital camera (Ophir Oprtonics).

3. Results and discussion

In experiments, the active media of the inductive HF laser were gas mixtures of hydrogen with fluorine containing compounds (F_2, NF_3, or SF_6). For buffer gases, we used helium and neon. The maximal energy of the laser pulse (6.3 mJ) was obtained in this laser emitter if NF_3 molecules in the mixture $H_2:NF_3 = 1:4$ were used as a donor of fluorine. Dilution of the mixture by helium or neon increased the energy by a factor of 1.5. The optimal part of a buffer gas in the working mixture was the same for He and Ne and corresponded to approximately 90%; the employment of helium provided a higher laser energy. The charge voltage in the experiments was 25 kV. With increasing voltage to 31 kV (a further increase was limited by the power supply system), the output energy increased actually linearly to 19 mJ (Fig. 1). In the following experiments we used the two-component mixture $H_2:NF_3 = 1:4$ or three-component mixture $He:H_2:NF_3 = 45:1:4$.

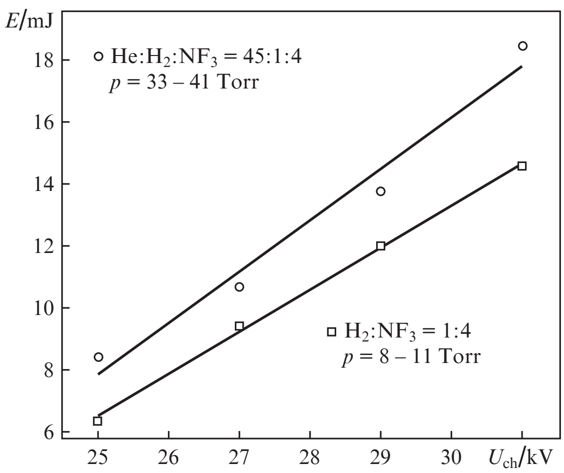

Figure 1. Output energy E vs. the charge voltage U_{ch} of the inductive HF laser with two- and tree-component mixtures.

The repetitively pulsed inductive HF laser operated at a pulse repetition rate of up to 3 Hz. In this regime, the pulse energy was 2–2.5 times less than the energy of single pulses. One may assume that this fact is directly related with an insufficient rate of the mixture exchange in the laser emitter. An improved construction with a higher rate of gas exchange may increase the pulse repetition rate to tens Hz without any loss in energy. It was also experimentally found that in the repetitively pulsed regime the instability of light pulses was at most 5%–6%.

The profile and duration of generation pulses of the HF laser pumped by an induction discharge have been investigated. A pulse oscillogram is shown in Fig. 2. The pulse base-level duration reached 7 μs, its FWHM duration was 0.42 μs and did not change at elevating the discharge voltage. Hence, we may assert that at the maximal generation energy of 19 mJ obtained on the mixture $He:H_2:NF_3 = 45:1:4$, the output pulse power was 45 kW.

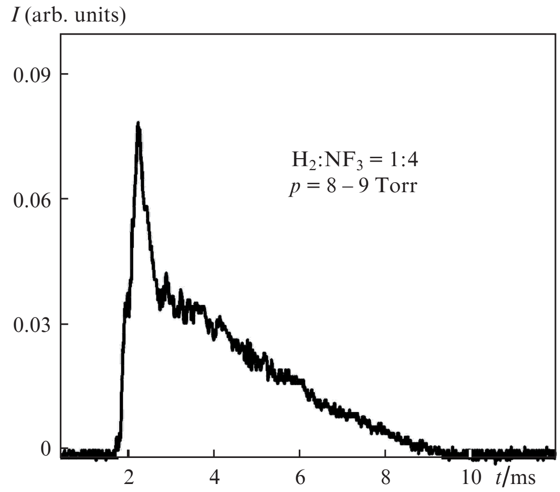

Figure 2. Oscillogram of an output pulse of the HF laser. The charge voltage is U_{ch} = 25 kV.

For the first time, a spectral composition of radiation of an inductive HF laser has been investigated. The spectrum was recorded in the range of 2600–3500 nm. It was found that the emission spectrum resides in a range of 2730–2910 nm and comprises seven bands with the centres near the wavelengths λ = 2732, 2763, 2798, 2835, 2873, 2893 and 2913 nm (Fig. 3). The most intensive are three groups in the range of 2760–2840 nm. The spectrum composition remained almost constant when the two-component mixture $H_2:NF_3 = 1:4$ was replaced with the three-component mixture $He:H_2:NF_3 = 45:1:4$, only negligible redistribution of intensities over some groups of bands occurred. Such a structure of the emission spectrum of an inductive HF laser makes it possible to vary the generation frequency over various groups (first of all, in the range of 2760–2840 nm).

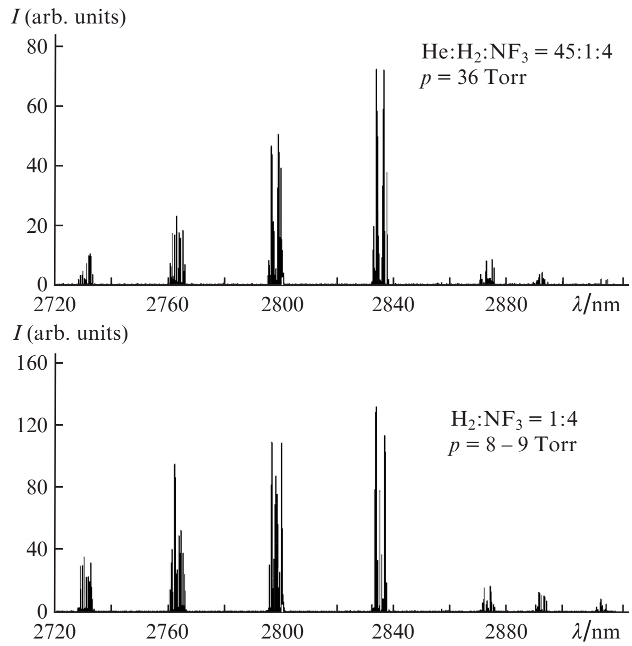

Figure 3. Emission spectrum of the inductive HF laser. The charge voltage is U_{ch} = 25 kV.

Analysis of literature data [9–12] shows that emission spectra of HF and DF lasers initiated by an electric discharge conventionally comprise several lines corresponding to various vibrational–rotational transitions in HF and DF molecules [9, 10]. For comparison, emission spectra of chain and gas-dynamic HF/DF lasers, as a rule, comprise a great number of lines close to each other and may strongly depend on the composition and pressure of the active medium [11, 12].

In our case, the emission spectrum included separate band groups, which is not typical of the HF lasers, so we plan to carry out additional investigations aimed at studying detailed structures of each group; however, in the present work such investigations were not performed. Spatial characteristics of laser radiation have also been measured. In Fig. 4, one can see a beam profile of an inductive HF laser. Since the active medium in our experiments had the shape of a hollow cylinder, the laser beam cross-section profile resembled a ring. Its external diameter was close to the inner diameter of the laser tube (20 mm), and the width was about 5 mm. The present work was not aimed at studying the mode composition of the output radiation; however, an analysis of the laser beam profile is indicative of multimode lasing. This may be related with the fact that in our experiments we employed a resonator of the type of an open Fabry–Perot interferometer with plane mirrors. A more thorough investigation of the mode structure of radiation and the possibility of an inductive HF laser to operate in the single-mode regime are tasks for future study.

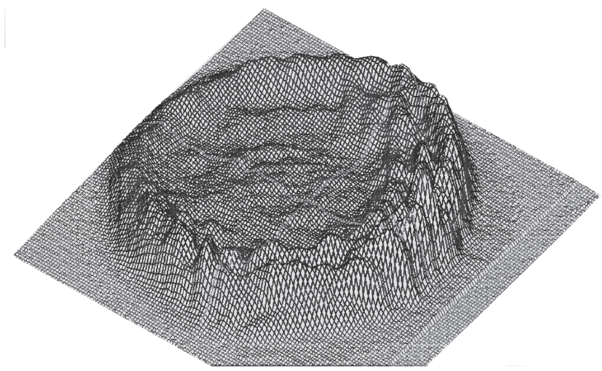

Figure 4. Profile of the output beam of the inductive HF laser. The charge voltage is $U_{ch} = 25$ kV, the mixture is $He:H_2:NF_3 = 45:1:4$.

4. Conclusions

Thus, temporal, spectral and spatial characteristics of generation of an inductive HF laser have been investigated under various pump conditions. Mixtures of hydrogen with F_2, NF_3 and SF_6 were used as active media; helium and neon were used as buffer gases. The maximal output energy of 19 mJ was obtained on the mixture $He:H_2:NF_3 = 45:1:4$ at a pressure of 41 Torr. The FWHM duration of laser pulses reached 0.42 μs, which corresponds to the pulsed power of 45 kW. The profile and duration of pulses weakly depend on the pump conditions. All the laser radiation is concentrated in the range of 2730–2910 nm and comprises seven bands around λ = 2732, 2763, 2798, 2835, 2873, 2893 and 2913 nm. The spectral composition is actually independent of the active medium contents; only the ratio of intensities of separate components varied. The cross-section profile of the beam was a ring with a diameter of about 20 mm and width of about 5 mm. The laser operation in the repetitively pulsed regime was stable. The instability of light pulses was at most 5%–6%.

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