Quantum Electronics **31** (3) 218 – 220 (2001) ©2001 Kvantovaya Elektronika and Turpion Ltd

PACS numbers: 42.55.Ks; 42.60.Jf
DOI: 10.1070/QE2001v031n03ABEH001920

Experimental study of a nonchain HF laser on heavy hydrocarbons

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***Abstract*. The output characteristics of a nonchain electric-discharge, closed cycle HF laser operating under pulsed and repetitively pulsed pumping with a rate of discharge current rise of $\sim 10^{10}$ A s^{-1} are experimentally studied. Using an anisotropically resistive cathode, a specific input energy of 200 J litre^{-1} in mixtures of heavy hydrocarbons with SF_6 [$SF_6 - (C_3H_8 + C_4H_{10})$] was obtained. An unstable telescopic cavity provided a nearly diffraction-limited divergence.**

Keywords: *nonchain HF laser, heavy hydrocarbons, anisotropically resistive electrode.*

1. Introduction

High-power repetitively pulsed gas lasers, especially lasers with a closed cycle of laser mixture circulation, can find application in a number of problems that require not only an ultimately high energy strength of emission, but also a long continuous laser operation. In Ref. [1], a repetitively pulsed CO_2 system of the master oscillator – amplifier type producing laser emission with an energy strength of the order of a few terawatts per steradian was reported. Further progress in this area of research can be obtained by using nonchain electrochemical HF(DF) lasers emitting at shorter wavelengths.

Until recently, the achievement of high radiation energies (powers) in nonchain HF(DF) lasers was limited by the volume discharge contraction. In Refs [2, 3], these problems were obviated by using laser mixtures containing hydrocarbons, which simultaneously served as H(D) donors and easily ionised impurities. The use of a pulsed voltage generator (PVG), which switched on the pump after a preliminary filling of a discharge region with conduction electrons, also favoured the solution of these problems. In this case, the rate of discharge current rise dI/dt was $(2 - 3) \times 10^{11}$ A s^{-1}.

Unquestionably, it is of interest to study nonchain HF(DF) lasers with pump rates $dI/dt \sim 10^{10}$ A s^{-1}, which enables one, in the case of success, to use well-developed pump systems for TEA CO_2 lasers with pump pulses 0.2 – 1.0 μs long. The aim of this paper is to find optimum conditions for obtaining high output characteristics of a nonchain HF laser operating on heavy hydrocarbons.

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Received 10 September 2000
Kvantovaya Elektronika **31** (3) 218 – 220 (2001)
Translated by A N Kirkin

2. Experimental setup

The experiments were carried out on the setup described in Ref. [4]. Its schematic diagram is presented in Fig. 1. The laser was designed around an aerodynamic tube with a closed cycle of laser mixture circulation, with a laser chamber *1* placed in its working region. The discharge was formed between electrodes **2** of size 90 mm × 900 mm, which were spaced by a 45-mm gap. In contrast to [4], the initial electron concentration in the discharge region was produced by a corona discharge at the electrode surface, which was initiated by switching on the pump voltage.

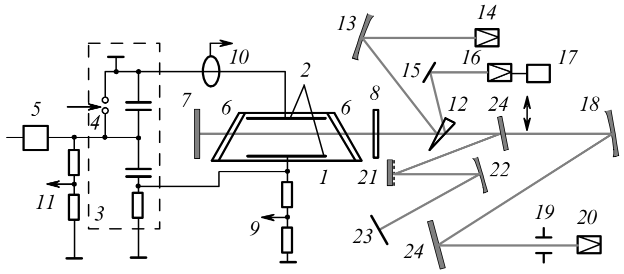

Figure 1. Schematic of the experimental setup: (*1*) laser chamber; (*2*) electrodes; (*3*) pulsed voltage generator; (*4*) multistage spark gap; (*5*) pulsed charging unit; (*6*) Brewster window; (*7, 8*) cavity mirrors; (*9, 11*) measuring voltage dividers; (*10*) Rogowski loop; (*12*) NaCl wedge; (*13, 18, 22*) focusing mirrors; (*14, 20*) calorimeters; (*15*) diffuse screen; (*16*) pyrodetector; (*17*) oscillograph; (*19*) aperture; (*21*) diffraction grating; (*23*) thermosensitive paper; (*24*) plane mirrors.

A PVG *3* had a one-stage Fitch design, and its switch represented a multistage pulsed spark gap *4*. When used in combination with a pulsed charging unit *5*, this pump system works in a repetitively pulsed regime with a frequency of up to 700 Hz. Windows *6* for the entrance and exit of radiation were made of NaCl and tilted to the axis of the laser chamber at the Brewster angle.

In the experiments, we used two types of cavities, namely, a plane cavity formed by a totally reflecting copper mirror *7* and a BaF_2 (ZnSe) plate *8* or an unstable telescope cavity (UTC) with magnification $M = 2$ and an output aperture 40 mm in diameter. The average flow velocity of a laser mixture in the repetitively pulsed mode of operation was held equal to 20 m s^{-1}.

In the experiments, we measured the discharge current, the voltage across the electrodes of the laser chamber, and the voltage charging the PVG. The laser radiation reflected from the front surface of a wedge *12* was directed to the system measuring the radiation power, which consisted of a focusing mirror *13* and an IMO-2N calorimeter *14*. The radiation reflected from the back surface of the wedge *12* was directed to the system measuring the laser pulse form, which consisted of a diffuse screen *15* and a pyrodetector *16* connected to an oscillograph *17*.

To eliminate electric disturbances from the PVG, the pyrodetector and the oscillograph were placed in a special screened chamber. The radiation transmitted through the wedge *12* was directed to the system measuring its angular divergence. It consisted of a concave mirror *18* with a focal distance of 6 m, changeable calibrated apertures *19*, which were placed in the focal plane of the mirror *18*, and a TPI-2M calorimeter *20*, which was placed behind apertures *19*. To record the HF laser emission spectrum, the mirror *18* was replaced with a diffraction grating *21* with the period $d = 10$ μm. The radiation reflected from the grating was directed by a focusing mirror *22* onto photosensitive paper *23*.

3. Experimental results and discussion

The measurements were carried out in pulsed and repetitively pulsed regimes, and the working pressure of a laser mixture was $p = 75$ Torr. We studied SF6 – (CH_3+ C_4H_{10}) laser mixtures of SF6 with technical-grade propane-butane in comparison with the $SF_6 - H_2$ mixture. The partial pressures taken in the ratio 30:1 were optimum for the given setup from the viewpoint of energy deposition.

First, aluminium electrodes and a plane cavity were used in the laser chamber. None of the regimes gave lasing in $SF_6 - H_2$ mixtures because electric breakdown developed there. In the $SF_6 - (C_3H_8 + C_4H_{10})$ mixture, the emission of the volume discharge was excited in a very narrow range of PVG charging voltages, not higher than 1 kV. In this case, the specific output energy was 0.7 J $litre^{-1}$, and emission of the volume discharge was very inhomogeneous. The highest emission intensity was observed at the edges of electrodes, from which electric breakdown developed in the majority of cases.

The behaviour and parameters of the discharge radically change after the replacement of the metal cathode with an anisotropically resistive electrode. The specific output power obtained in the SF6 – ($C_3H_8 + C_4H_{10}$) mixture increased by a factor of five, and the emission of the volume discharge became homogeneous. In the pre-breakdown phase of the discharge, we observed the growth of current filaments from the anode, and breakdown developed from one of them. The specific output energy of the $SF_6 - H_2$ mixture did not exceed 1 J $litre^{-1}$. In the case of the unstable telescopic cavity with $M = 2$ and an output aperture 40 mm in diameter, the specific output energy increased by 25 % compared to the plane cavity of the same volume. This is explained by the fact that the unstable telescopic cavity with $M = 2$ is close to the optimum cavity for the given laser. Note that upon the replacement of the output BaF_2 mirror in the plane cavity with the ZnSe mirror, the output radiation parameters remained almost unchanged.

Fig. 2 presents the results of measuring the specific output radiation energy as a function of the input energy, which was defined as the energy stored in the PVG. The measurements of discharge parameters and the calculation of its energy by the formula

$$W^{el} = \int_0^{\tau} U(t)I(t)\mathrm{d}t,$$

where τ is the pump pulse duration, $U(t)$ and $I(t)$ are the voltage and the discharge current, showed that no less than 65 % of the energy stored in the PVG was deposited in the volume discharge. The quasistationary discharge phase is characterised by the ratio $E/p \sim 80 - 120$ V cm^{-1} $Torr^{-1}$.

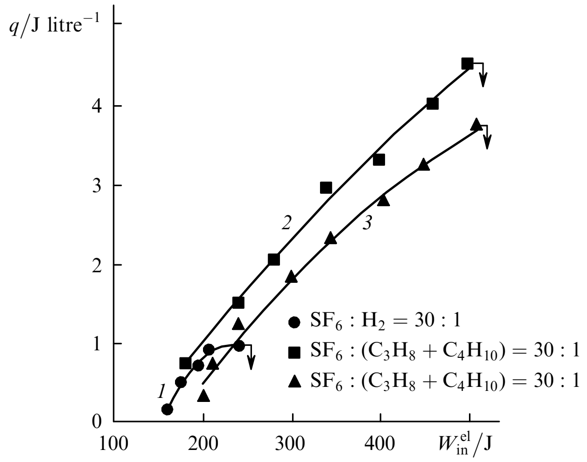

Figure 2. Dependences of the specific radiation energy q on the input energy W_{in}^{el} for the $SF_6 - H_2$ mixture and the plane cavity with aperture 45 × 90 mm (*1*), the $SF_6 - (C_3H_8 + C_4H_{10})$ mixture and the unstable telescopic cavity with $M = 2$ and $d = 40$ mm (*2*), and the $SF_6 - (C_3H_8 + C_4H_{10})$ mixture and the plane cavity with aperture 45 × 90 mm (*3*); the arrows show the threshold of electric breakdown.

Fig. 3 presents typical oscillograms of voltage across the electrodes of the discharge chamber, the discharge current, and the laser radiation pulse.

The efficiency of the anisotropically resistive electrode consists in the fact that it enables one to counterbalance the negative discharge resistance $\mathrm{d}U/\mathrm{d}t$ in the near-cathode region by an anisotropically resistive cathode region that is connected in series. In this case, the resistance of this cathode region $R_c = rl/s$ (r, l, and s are the resistivity, the length of this cathode region, and its area) should exceed $-\mathrm{d}U/\mathrm{d}I$. In our case, $r = 45$ Ohm cm^{-1}.

We made comparative measurements of radiation divergence for the plane cavity and the unstable telescopic cavity with $M = 2$. The measurements were made by the method of calibrated apertures [1] for the same output apertures, which were 40 mm in diameter. The results of divergence measurements are presented in Fig. 4. For the unstable telescopic cavity, the divergence θ was equal to $1.7\theta_{dif}$, and it was independent of the input energy throughout the measurement range. An insignificant distinction of divergence from the diffraction limit is attributed to the imperfection of optical elements used in the laser and the inaccuracy of cavity alignment. The divergence obtained for the plane cavity was typical of the given cavity type, $\sim 10\theta_{dif}$.

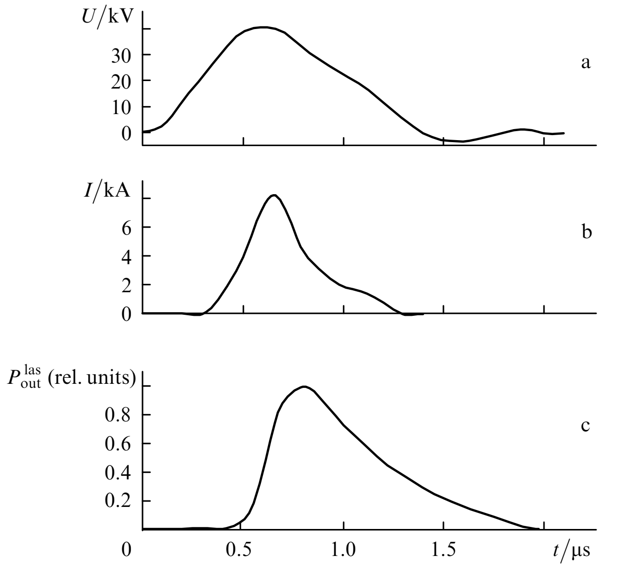

Figure 3. Oscillograms of voltage across the discharge gap (a), discharge current (b), and laser radiation power (c).

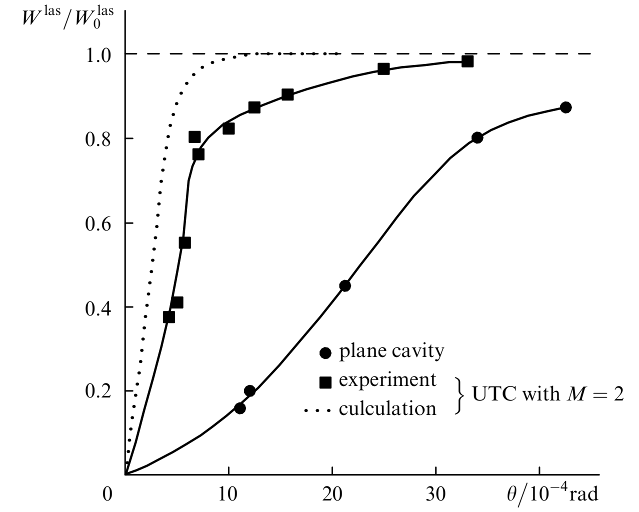

Figure 4. Normalased energy distribution of emission as a function of the angle embraced by the aperture diaphragm for the output aperture diameter 40 mm.

Fig. 5 presents the results of our study of the HF laser in the repetitively pulsed mode of operation. The maximum deposited energy was reached at a frequency of 90–100 Hz. Note that the operation of the HF laser in this mode is similar to the operation of the well-studied TEA CO_2 laser.

The studies of long-term laser operation with different mixture compositions showed (Fig. 6) that the radiation power decreased mainly due to the relaxation of excited HF molecules because the power deposited in the discharge remained constant until a complete disappearance of lasing. The employment of systems for regeneration of exhausted laser mixtures [5] will make it possible to stabilise the laser radiation power at a required level.

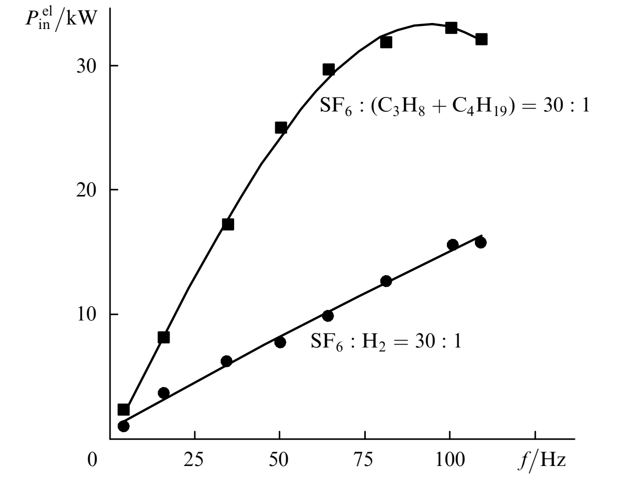

Figure 5. Dependence of the input power on the pulse repetition rate for $SF_6-(C_3H_8+C_4H_{10})$ and SF_6-H_2 mixtures.

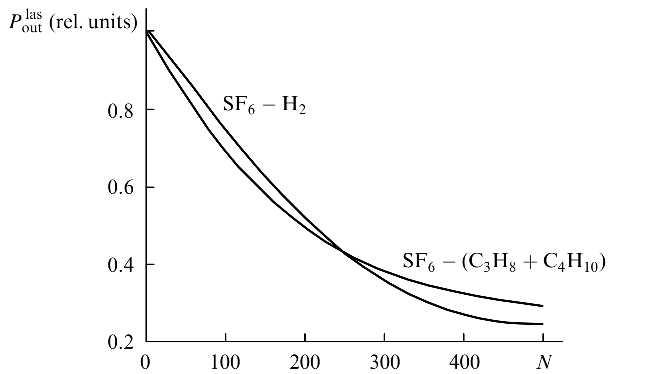

Figure 6. Dependences of the radiation power of the HF laser on the number of emitted pulsed for $SF_6-(C_3H_8+C_4H_{10})$ and SF_6-H_2 mixtures.

4. Conclusions

We have experimentally confirmed the feasibility of obtaining high output parameters in nonchain HF(DF) lasers. The output power of HF(DF) lasers can be further increased by using an anisotropically resistive anode and increasing the discharge volume up to tens and hundreds of litres.

References

1. Babaev I K, Bardakovskii, Blinov N A, et al. *Kvantovaya Elektron.* **18** 6 (1991) [*Sov. J. Quantum Electron.* **21** 2 (1991)]
2. Apollonov V V, Kazantsev S Yu, Oreshkin V F, Firsov K N *Kvantovaya Elektron.* **24** 213 (1997) [*Quantum Electron.* **27** 207 (1997)]
3. Apollonov V V, Kazantsev S Yu, Oreshkin V F, Firsov K N *Kvantovaya Elektron.* **25** 123 (1998) [*Quantum Electron.* **28** 116 (1998)]
4. Bulaev V D, Vidavskii A E, Kovalev V I, Kulikov V V *Kvantovaya Elektron.* **25** 243 (1998) [*Quantum Electron.* **28** 235 (1998)]
5. Velikanov S D et al. *Kvantovaya Elektron.* **25** 295 (1998) [*Quantum Electron.* **28** 285 (1998)]