文章编号 1674-2915(2011)01-0026-05

High power pulse-periodical electrochemical HF laser

BULAEV V D[1], GUSEV V S[1], FIRSOV K N[2], KAZANTSEV S Yu[2],
KONONOV I G[2], LYSENKO S L[1], MOROSOV Yu B[1], POZNYSHEV A N[1]

(1. *Federal State Unitary Enterprise Kosminov State Scientific Research Test Laser Center(Range) of the Russian Federation《RADUGA》, Raduzhnyi, Vladimir Region, Russia*
2. *Prokhorov General Physics Institute, Russian Academy of Science, Moscow* 119991, *Russia*)

Abstract: The high power nonchain repetitively pulsed HF laser is developed and the possibility of realizing the self-sustained volume discharge in SF_6-based mixtures in the discharge gap with a high edge enhancement of the electric field without any additional stabilization measures in a pulsed discharge as well as in pulse-periodic modes is investigated. The obtained laser energy is 67 J at the efficiency in 3% and pulse repetition rate in 20 Hz.

Key words: chemical laser; non-chain pulsed HF laser; self-sustained volume discharge; SF_6-based mixture

高功率重频电化学 HF 激光器

BULAEV V D[1], GUSEV V S[1], FIRSOV K N[2], KAZANTSEV S Yu[2],
KONONOV I G[2], LYSENKO S L[1], MOROSOV Yu B[1], POZNYSHEV A N[1]
(1. 国家科学研究中心激光实验室,俄罗斯,弗拉基米尔地区;
2. 俄罗斯科学院 普罗霍罗夫普通物理研究所,莫斯科 119991)

摘要:研制了高功率、高重频非链式 HF 激光器,并研究了脉冲模式和重频模式下在 SF_6 的混合气中增加电极边缘电场强度而不使用其它措施即可实现自持体引发放电的可能性,得到了重复频率为 20 Hz,脉冲能量为 67 J,转换效率为 3% 的激光输出。

关　键　词:化学激光器;非链式脉冲 HF 激光器;自引发体放电;SF_6 混合气体
中图分类号:TN248.5　　**文献标识码**:A

收稿日期:2010-08-21;**修订日期**:2010-10-15
基金项目:Supported by Russian Foundation for Basic Research Project(Grants No. 09-02-00475, No. 08-08-00242).

1 Introduction

Now nonchain electric discharge HF(DF) lasers are unique ecologically safe sources with high peaks and average generation powers at close to the diffraction limit of laser beam divergence in a practically important area of spectrum $\lambda = 2.6/4.2$ μm. Such sources represent doubtless interest not only for monitoring an atmosphere[1,2], but also for carrying out some physical experiments on interaction IR radiation with liquids[3,4] and for optical pumping other gas lasers of IR range[5-7], including obtaining short pulse[8] and powerful generation in the terahertz region of the spectrum[9].

The purpose of the present work is to research an opportunity of achievement of the big radiation energy in a pulse-periodic mode of functioning the nonchain electric discharge HF laser with continuous metal electrodes in absence of additional measures on stabilization of Self-sustained Volume Discharge (SVD).

2 Experiments

Experimental installation looked as follows. The discharge gap of the laser has been formed by two identical flat electrodes from the duralumin, rounded on perimeter in radius $r = 2$ cm. The size of a flat part of a surface of electrodes made 15 cm × 100 cm. The interelectrode distance could vary in limits d = 10/20 cm, experiments were carried out at d = 15 cm. The electrode which was used as the cathode has been subjected to sandblasting with the purpose of formation on its surface small-scale nonuniformity (~50 μm), that, as shown in Ref. [10], facilitates development the self initiating volume discharge. Electrodes were placed in to a glass-epoxide tube with internal diameter 80 cm and length 250 cm symmetrically and were relative its axes. Photograph of the electrode system, available through the output window of the discharge chamber is shown in Fig. 1.

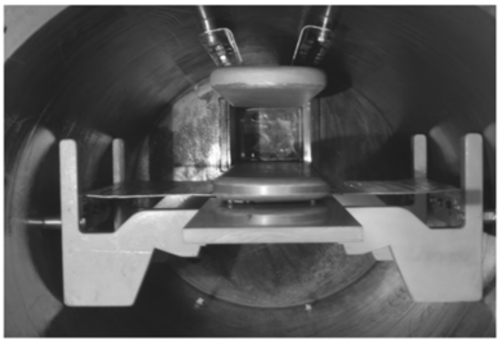

Fig. 1　Discharge chamber with electrode system.

The working mixtures of the laser $SF_6 : C_2H_6$ = 20:1, $SF_6 : C_3H_8C_4H_{10}$ = 30:1 and $SF_6 : H_2$ = 9:1 with the full pressure about 6/10 kPa were used. Change of working mixtures in volume discharge was provided due to circulation of gas in the closed contour. For this purpose it was applied the special fan block similar described in Ref. [11]. The gas mixtures were blown along an axis of the discharge chamber, speed of a stream in the discharge zone made 40 m/s.

The resonator of the laser has been formed by a copper mirror with the radius of curvature R = 20 m and a plane-parallel plate from KCl. The mirror was installed in the adjusting unit connected to the flash chamber by sylphon. The plane-parallel plate fastened directly at an end face of the discharge chamber. The radiation energy of the laser was measured in a single pulse mode with the help of a matrix of calorimeters such as E-60 with the size of 18 cm × 18 cm, installed in a direct laser beam on distance of 1 m from a window of the discharge chamber.

The pulse high-voltage generator using for formation SVD consist of 4 identical sections, connected in parallel to electrodes of a discharge gap copper trunks. Sections are placed in the uniform metal case filled SF_6 at atmospheric pressure. Sections of the generator are collected under two-level Fitch circuit on low inductive condensers C = 50 nF with rated voltage 100 kV marking KMKI-100-50. Electric

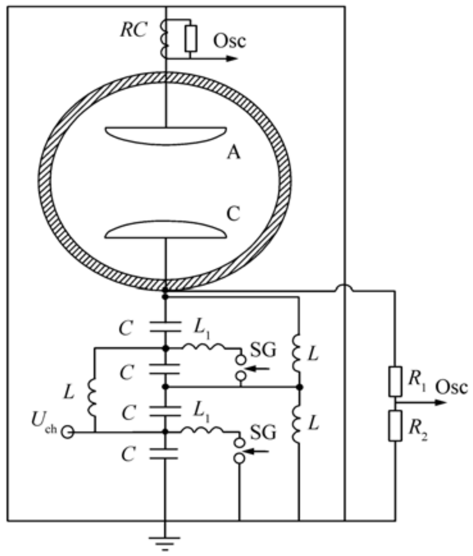

Fig. 2 Electric circuit of Fitch high-voltage generator (one of 4 section).

circuit used in high-voltage generator is shown in Fig. 2. Controlled spark-gaps[12] are filled with mixtures SF_6:N_2 = 1:10 with overpressure up to 6 bars. The construction of spark-gaps allows to operate the laser by duration up to 60 s with frequency of following of discharge pulses in 20 Hz without replacement in them of gas. Charging voltage U_{ch} in experiments varied in limits U_{ch} = 50/75 kV. In a circuit of spark-gaps, the inductance using for the coordination of a contour of polarity inversion of a voltage on the condenser with a discharge contour was fitted experimentally. The pulse voltage of the discharge was measured by a resistive divider, and a pulse current was measured by a Rogowski coil covering a part of the current carrying trunk. Such quality monitoring at the big trunks width(~1 m in examined installation) does not give an opportunity of exact measurements of a discharge current, but allows to determine its maximum time position. The system of synchronization provides simultaneous start 8 spark-gaps of the high-voltage generator with accuracy ±10 ns.

3 Results and discussion

After the coordination of a contour of polarity inversion of the condenser in Fitch generator with a discharge contour steady SVD in mixtures SF_6 with hydrocarbons has been received in all range of voltage change U_{ch} = 50/75 kV at frequency of following of discharge pulses up to 20 Hz. Opportunities of the further increase in frequency of following were limited to speed the change of a working gas mix in a discharge chamber. Fig. 3 shows a photograph of SVD in a mixture SF_6 : C_2H_6 at the maximum charging voltage in U_{ch} = 75 kV, illustrating the uniformity of SVD in high edge to strengthen the electric field, which is characteristic for the intervals used here type. Fig. 4 shows the distribution of the intensity of the glow discharge plasma to coordinate a plane par-

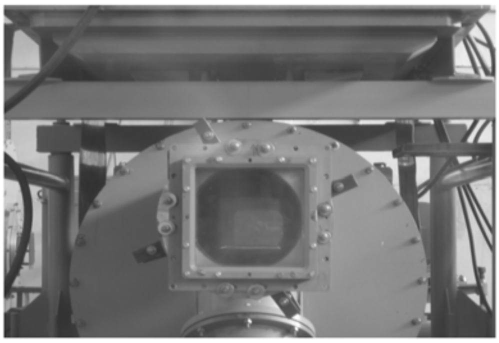

Fig. 3 Photograph of discharge chamber (front view) and SVD in mixtures SF_6:C_2H_6 = 20:1.

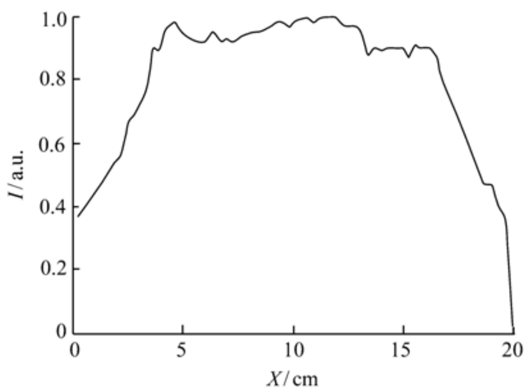

Fig. 4 Distribution of intensity glow of discharge plasma to coordinate a plane parallel to the surface of electrodes.

allel to the surface of the electrodes. The distribution reflects the distribution of input power for the interval[14]. Fig. 4 shows that, despite the marginal gain of the electric field, the maximum energy deposition is achieved in the central zone of the gap. Fig. 5 shows typical oscillograms of the voltage across the discharge gap and discharge current when the ignition SVD in a mixture of SF_6: C_2H_6. These oscillograms allow with sufficient accuracy to estimate the duration of the discharge current $t_{dis} \approx 320$ ns. With such a relatively large, the duration of the input electrical energy into the discharge plasma in mixtures of SF_6 with hydrogen SVD is stable only in the charging voltages $U_{ch} \leqslant 60$ kV. In mixtures of SF_6 with the same hydrocarbons as follows from the above experimental data, SVD implemented in the whole range of U_{ch} without whatever additional measures to stabilize it as a pulse and a pulse-periodic modes of the HF laser. Laser pulse was typical nonchain electric discharge HF laser form[13], its duration at half amplitude was about 150 ns, the generation began near the current maximum.

Experimentally dependence of radiation energy W_g from charging voltage is submitted on Fig. 6. Apparently from Fig. 6, the maximal energy of generation $W_g = 67$ J is reached on mixtures SF_6: C_2H_6, at $U_{ch} = 75$ kV, that corresponds to electric efficiency ~3% on energy, reserved in condensers. Low efficiency of the laser on mixtureses SF_6 with hydrogen is caused, apparently, by pumping heterogeneity because of rather big duration of a discharge current. We shall also note, that in the present work the efficiency is lower than that in Ref. [14] at close characteristics of a discharge gap and identical structures of a mixtures. Probably, the given fact can be connected to the big losses of electric energy in circuits of the Fitch generator.

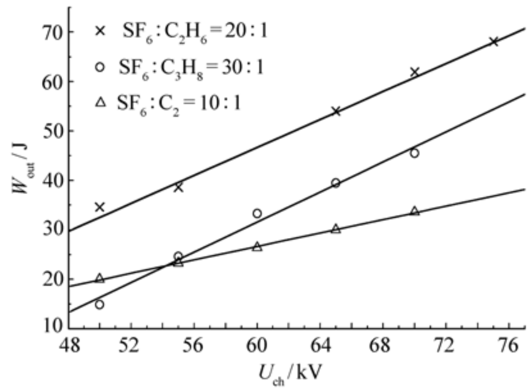

Fig. 6　Dependences of laser generation energy W_g from U_{ch} at use different mixtures of hydrocarbons

4　Conclusions

Thus, by us it is developed and investigated powerful the nonchain electric discharge repetitively pulsed HF laser. The opportunity of realization SVD on mixtures SF_6 with hydrocarbons in a discharge gap with high edge electric field gain without additional measures of stabilization of the discharge both in pulse, and in a repetitively pulsed mode is shown. Laser generation energy W_g = 67 J is received at frequency of pulses following of 20 Hz.

In summary, we shall notice that, for reception of generation on DF as the donor of deuterium can be used C_6D_{12}. Stability SVD in mixtures SF_6 with deuterocarbons, as is known, not worse, than in mixes with hydrocarbons, and energy of generation on DF in identical conditions on pumping in plasma of the discharge makes ~0.8 from energy of generation on HF[15].

References:

[1]　VELIKANOV S D, ELUTIN A S, KUDRYASHOV E A, *et al.* Use of a DF laser in the analysis of atmospheric hydrocarbons [J]. *Quantum Electron*, 1997, 27(3), 273-276.

[2]　AGROSKIN V Y, BRAVY B G, CHERNYSHEV Y A, *et al.*. Aerosol sounding with a lidar system based on a DF laser [J]. *Appl. Phys. B*, 2005, 81: 1149.

[3]　ANDREEV S N, FIRSOV K N, KAZANTSEV S Y, *et al.*. Explosive boiling of water induced by the pulsed HF-laser radia-

tion[J]. *Laser Phys.* ,2007,17(6):834.

[4] ANDREEV S N,KAZANTSEV S Y,KONONOV I G,*et al.*. Temporal structure of an electric signal produced upon interaction of radiation from a HF laser with the bottom surface of a water column[J]. *Quantum Electron*,2009,39(2):179-184.

[5] BURTSEV A P,BURTSEVA I G,MASHENDZHINOV V I,*et al.*. New HBr-laser with resonant optical pumping by DF-laser radiation[J]. *SPIE*,2004,5479:174-176.

[6] ALEXANDROV B S,ARSENJEV A V,AZAROV M A,*et al.*. Increase of efficiency of optical pumping of a broadband CO_2 laser amplifier as a result of the use of a multicomponent active medium[J]. *SPIE*,2003,5120:551-556.

[7] AZAROV M A,ALEXANDROV B S,ARSENJEV A V,*et al.*. High pressure with optical pumping by HF laser radiation [J]. *SPIE*,2007,6346:63462B.

[8] VASILIEV G K,MAKAROV E F,CHERNYSHEV Y A. Optical pumping of the N_2O-He and N_2O-CO_2—He mixtures by a pulsed multifrequency HF laser for producing active media to amplify 10-μm high-power ultrashort pulses[J]. *Quantum Electron*,2005,35(11):987-992.

[9] SKRIBANOWITZ N,HERMANN I P,MACGILLIVRAY M S,*et al.*. Observation of dicke superadiance in optically pumped HF gas[J]. *Phys. Rev. Lett.* ,1973,30:309-312.

[10] APOLLONOV V V,BELEVTSEV A A,KAZANTSEV S Y,*et. al.*. Self-initiated volume discharge in nonchain HF lasers based on SF_6-hydrocarbon mixtures[J]. *Quantum Electron*,2000,30(3):207 -214.

[11] BULAEV V D,KULIKOV V V,PETIN V N,*et al.*. Experimental study of a nonchain HF laser on heavy hydrocarbons [J] . *Quantum Electron*,2001,31(3):218-220.

[12] GORNOSTAY-POLSKY S A,GRISHIN A V,BALYABIN M G,*et al.*. High-current gas-filled spark-gap:RU, 2241288 [P]. 2004-11-27.

[13] APOLLONOV V V,KAZANTSEV S Yu,ORESHKIN V F,*et al.*. Feasibility of increasing the output energy of a nonchain HF(DF) laser[J]. *Quantum Electron*,1997,27(3):207-209.

[14] ANDRAMANOV A V,KABAEV S A,LAZHINTSEV B V,*et al.*. Formation of the beam profile in a plate electrode HF laser[J]. *Quantum Electron*,2005,35(4):359-364.

[15] BELEVTSEV A A,FIRSOV K N. The encyclopedia of law-temperature plasma[M]. Moscow:Physmatlit,2005,XI-4:761.

Author′s biography:Sergey Kazantsev(1971—), Moscow, Russia, graduated from Moscow Engineering Physics Institute(State University) in 1998, His research interests are concerned with experimental investigation of volume self-sustained gas discharge phenomena, development of chemical and high-power electric discharge lasers, and investigation of high power laser beam interaction with matter, laser induced gas breakdown, laser lightning protection. E-mail:kazan@ kapella. gpi. ru