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Electrode system for electric-discharge generation of atomic iodine in a repetitively pulsed oxygen – iodine laser with a large active volume

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Abstract. **Possibilities for increasing the active medium volume of a chemical oxygen – iodine laser (CCOIL) with a pulsed electric-discharge generation of atomic iodine are studied. The reasons are analysed of the low stability of the transverse self-sustained volume discharge in electrode systems with metal cathodes under the conditions of the electric energy input into gas-discharge plasma that are typical for CCOILs: low pressure of mixtures containing a strongly electronegative component, low voltage of discharge burning, low specific energy depositions, and long duration of the current pulse. An efficient electrode system is elaborated with the cathode based on an anisotropically-resistive material, which resulted in a stable discharge in the mixtures of iodide (CH_3I, n-C_3H_7I, C_2H_5I) with oxygen and nitrogen at the specific energy depositions of ~ 5 J L^{-1}, pressures of 10 – 25 Torr, and mixture volume of 2.5 L.**

Keywords: *pulsed chemical oxygen – iodine laser, volume self-sustained discharge, anysotropically-resistive material, electronegative gases, iodide.*

1. Introduction

Interest in investigations and elaboration of a chemical oxygen – iodine laser (COIL) is explained by its possible employment in industry (see [1] and references therein). In some technical applications the repetitively pulsed regime of the COIL operation with high peak power is preferable to the cw regime [2]. Pulsed longitudinal [3, 4] or transverse [2, 5] electrical discharges that burn directly in the laser gas medium comprising the mixture of singlet oxygen with an iodide and buffer gases can be used for realising such operation regimes. Atomic iodine is generated in the mixture for a relatively short period that is determined by the current discharge duration in the result of iodine dissociation by an electron impact, which provides the laser operation in a pulsed regime. In creating a COIL with a large active volume and, respectively, greater radiation energies the transverse self-sustained volume discharge (SVD) seems more promising than longitudinal one. Operation of the first repetitively pulsed COIL initiated by the SVD with the discharge volume of 52 cm^3 was reported in [2]. In [5], the active medium volume was increased to 625 cm^3. The specific output energy in [2] and [5] was ~ 1 J L^{-1}. Authors of both these works encountered the stability problem of self-sustained volume discharge in working mixtures of the COIL, which required special stabilisation measures. In [2], the resistive stabilisation of the current through separate sections of the cathode was used. The cathode was made of metal rods loaded to ballast resistors. In [5], edge electrodes of a special profile were connected to the current source through identical inductors [6]. Thus, the low SVD stability may be a principal difficulty in enhancing the energy characteristics of COILs with pulsed electric-discharge generation of atomic iodine.

This work is aimed at investigating possibilities of a further increase of the COIL active volume by improving the discharge stabilisation methods. The reasons of the low SVD stability are analysed and the efficient electrode system is suggested for obtaining the SVD in volumes of ~ 2.5 L.

2. Experimental setup

The conditions for obtaining the SVD in working COIL mixtures were modelled for the mixtures $RI:O_2:N_2 = (5-10):(50-150):(150-500)$, where RI are iodides CH_3I and n-C_3H_7I or C_2H_5I. The relatively low total pressure of the gas mixtures under study was determined by characteristics of the singlet oxygen generator in various installations.

Much of the low pressure of working mixtures used in [2, 5] causes problems with realisation of a stable transverse SVD. The low pressure at small contents of a strongly electro-negative component in the mixture is the reason, in turn, for the low voltage of SVD burning in real reachable 5 – 10-cm discharge gaps and the low electric field intensity E in the positive column of the discharge and at the cathode. Due to this fact and to the small average specific energy depositions into the plasma of the active medium of the COIL with electric-discharge generation of atomic iodine ($W_{el} = 2 - 10$ J L^{-1} [2, 5]), the SVD even in the form of a self-initiated volume discharge [7, 8] in the systems with solid metal cathodes has the form of diffuse channels sparsely distributed over the gap, which are bound to cathode spots because the surface density of spot distribution is proportional to the product EW_{el} [7]. A long duration of the current discharge pulse caused by a large capacitance of the pumping capacitor (that is determined by the condition for obtaining a prescribed parameter W_{el} at

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low voltage across the gap and, consequently, low voltage across the capacitor) also deteriorates the SVD homogeneity due to the developing plasma instability. Obviously, such a discharge cannot form the active medium of the COIL with the homogeneity required for obtaining efficient generation.

Sectioned electrodes along with the resistive or inductive stabilisation of the current [2, 5] allow one to realise the SVD; however, the gas-discharge plasma in this case does not fill the entire volume of the discharge gap but only a part of it, which reduces the effective active medium length at the extremely low small-signal gain, which is specific for COILs. In this work we attempt to avoid these drawbacks by employing the electrode system with the cathode based on an anisotropically-resistive material for obtaining the SVD in the working mixtures of the COIL. Anisotropically-resistive SVD stabilisation was suggested in [9]. In [10, 11], the SVD with a high specific energy deposition was obtained in the working mixtures of high-power nonchain HF(DF) lasers.

The setup employed in investigations is schematically shown in Fig. 1. The discharge gap cathode was made as follows. A rectangular 10-mm-thick plate with the dimensions 12×65 cm made of an anisotropically-resistive material described in [10] was attached to a duralumin plate by a conductive glue. The specific resistance of the cathode in the direction of electric field measured in a separate experiment by the dependence of the voltage across the electrodes on the SVD current in SF_6 was 26 Ω cm. The anode made of aluminum had the Chang profile with the curvature parameter $K = 0.554$. The separation between the electrodes was 5 cm. The SVD was initiated by the barrier discharge that burned between two wires in a polyethylene envelope, strained along the electrodes and connected to the cathode, and the anode under the voltage applied across the gap. In the experiments, we varied the horizontal distance between the wires (see Fig. 1) and separation between the wires and anode surface. According to preliminary estimates, this electrode structure should provide the SVD in the volume $V = 5 \times 10 \times 50$ cm. The electrodes were placed into a perspex chamber with windows for taking picture of the discharge.

The capacitor $C = 120$ nF discharged across the gap, the charge voltage varied from 6 to 15 kV ($W_{\text{el}} \sim 0.86$–5 J L^{-1}). The SVD current and voltage across the gap were controlled by means of a low-inductive shunt and resistive voltage divider, respectively.

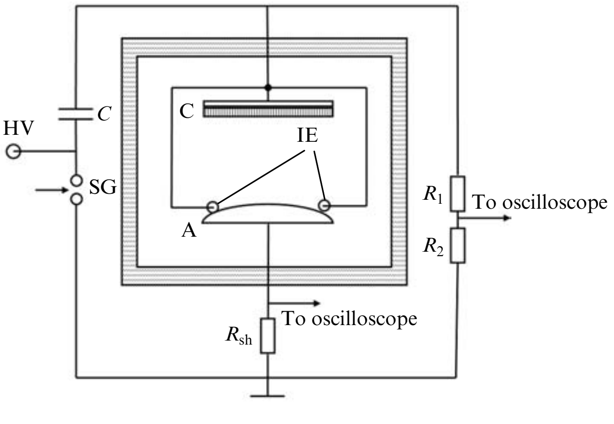

Figure 1. Electrical schematic of setup: (HV) high voltage; (SG) controlled spark gap; (A) anode; (C) cathode; (IE) initialising electrode; (R_{sh}) current shunt; (R_1) and (R_2) high-voltage voltage divider; $C = 120$ nF.

3. Experimental results and discussion

The SVD was obtained in all the gas mixtures under study at all energy depositions. Figure 2 presents typical oscillograms for the voltage across the gap and SVD current. One can see that the current pulse duration is ~ 1 μs. A model experiment with the current duration increased by inserting an additional inductance into the discharge circuit shows that in the considered electrode scheme the SVD stability is maintained at duration τ, at least, up to 1.5 μs over the entire range of the charge voltage variation. This confirms the possibility of further enlarging the discharge volume even without sectioning the pump source. Note that the electrical energy loss in the anisotropically-resistive cathode is small, because its own resistance at so large area ($\sim 10 \times 50$ cm) does not exceed 0.05 Ω at the discharge circuit impedance $\rho = \sqrt{L/C} \approx 2.7$ Ω (L and C are the inductivity of the discharge circuit and the capacitance of the pump capacitor, respectively).

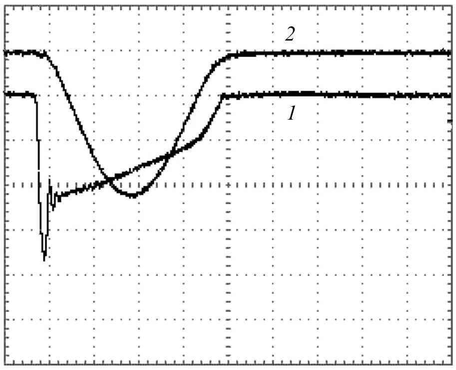

Figure 2. Oscillograms of the voltage across the discharge gap (*1*) and current (*2*) in the $C_2H_5I:O_2:N_2 \approx 6:50:150$ mixture at a pressure of 12 Torr obtained at the prescribed voltage of 11 kV. Scales along the vertical axis: voltage – 2.2 kV div.$^{-1}$, current – 625 A div.$^{-1}$; time scan – 250 ns div.$^{-1}$.

We found in the experiments that the distribution of energy deposited into SVD plasma over the discharge gap depends not only on the distribution of the electric field strength determined by the profile of electrode surfaces (in the considered case by the anode profile) but also on the spatial position of the initialising electrodes (IE, see Fig. 1). In this connection, the IE position was optimised with respect to the separation between the electrodes (a horizontal distance in Fig. 1) and to the distance from them to the anode surface (a vertical distance in Fig. 1) in order to obtain the most homogeneous distribution of energy deposition. The energy deposition was tested by SVD photographs. The optimal IE position is shown in Fig. 1: the initialising electrodes touch the anode surface and the separation between the electrodes is 14 cm.

Figure 3 illustrates the gas-discharge plasma homogeneity when the anisotropically-resistive cathode is used. The SVD photograph was obtained under the same conditions as the voltage and current oscillograms shown in Fig. 2. One can see that almost the entire cathode surface is tightly occupied by small cathode spots whose diameter is determined by the diameter of the conducting carbon fibres forming the cathode. In Fig. 4, the distribution of the plasma luminescence intensity is presented along the horizontal coordinate in the plane parallel to the cathode surface. The distribution was obtained by processing the photograph from Fig. 3 and qualitatively illustrates the distribution of energy deposition. One can see that the half-height width of the intensity distribution is ~ 0.7 cm. More plane distribution may be obtained by correspondingly varying the curvature parameter of the anode profile.

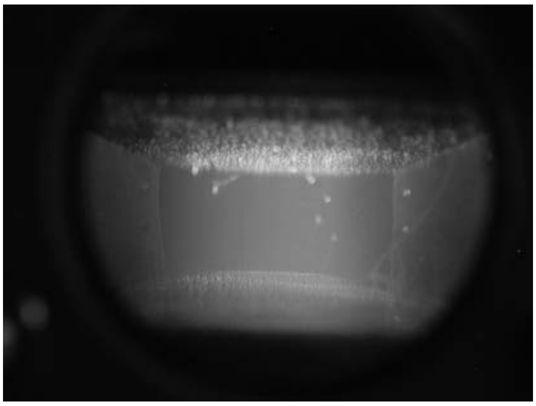

Figure 3. SVD photograph in the $C_2H_5I:O_2:N_2 \approx 6:50:150$ mixture at a pressure of 12 Torr and the charging voltage of 11 kV.

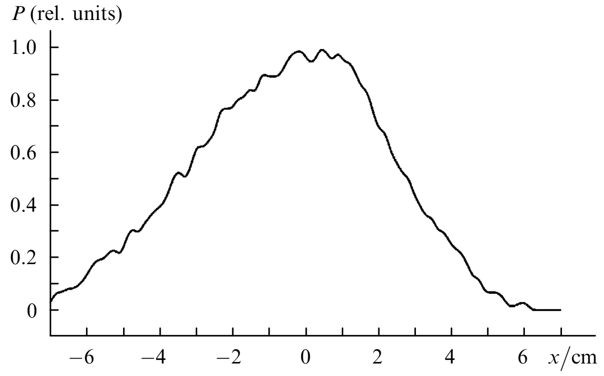

Figure 4. Distribution of the glow intensity P of the discharge plasma along the x axis in the plane parallel to the surfaces of electrodes.

4. Conclusions

Thus, employment of the cathode on the basis of an anisotropically-resistive material helps to realise a transverse SVD in large volumes of working mixtures of a COIL with electric-discharge generation of atomic iodine. A similar cathode was successfully employed [11] in a high-power repetitively pulsed HF laser with the pulse repetition frequency of up to 100 Hz and the parameter $W_{\rm el}$ exceeding 100 J L^{-1}. In this connection there is no doubt in the possibility of realising the repetitively pulsed regime in the case of the considered electrode system in the COIL, for which the optimal values of the parameter $W_{\rm el}$ are 2–3 J L^{-1} [2, 5].

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