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# Influence of gas temperature on self-sustained volume discharge characteristics in working mixtures of a repetitively pulsed COIL

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*Abstract.* **The influence of gas temperature on the characteristics of a self-sustained volume discharge was studied in the working mixtures of a chemical oxygen–iodine laser with pulsed electric-discharge production of iodine atoms. In experiments, laser working mixtures were modelled by the mixture of air and iodide $C_2H_5I$. It was established that mixture heating is accompanied by an increase in the voltage across the discharge plasma and by a decrease in the discharge current. By varying the temperature of the mixture with the iodine content of ~2.7 % and initial pressure $p$ = 12 Torr from 22 °C to 96 °C, the current amplitude falls by ~12 %, and at the instant corresponding to a maximal current the voltage raises by ~22 %. Such a change in the discharge characteristics is explained by a higher rate of electron attachment to vibrationally excited iodide molecules at elevated temperatures.**

**Keywords:** *repetitively pulsed chemical oxygen–iodine laser, self-sustained volume discharge, critical reduced electric field.*

In recent years a high interest was paid to the development and investigation of repetitively pulsed chemical oxygen–iodine lasers (RP COILs) with the production of atomic iodine in a self-sustained volume discharge (SVD) [1–6]. This interest is caused by a considerably wider range of possible applications of such lasers as compared to conventional cw chemical oxygen–iodine lasers (COILs) [1]. However, the physics of a SVD in working mixtures of RP COILs has not been studied completely yet. Typical gas mixtures of RP COILs with the production of atomic iodine in the SVD comprise strongly electronegative component iodide ($CH_3I$ or $C_2H_5I$), singlet oxygen $\Delta^1O_2$, oxygen in the fundamental state, and a buffer gas, usually $N_2$. It was established [7] that the value of the critical reduced electric field $(E/p)_{cr}$ ($E$ is the field strength, and $p$ is the pressure) for singlet oxygen is lower than for oxygen in the fundamental state. The numerical model was developed in the same work, which adequately describes experimental data. According to [7], one may expect that the voltage across SVD plasma in the COIL will depend on the content of $\Delta^1O_2$ in the mixture, and a variation in the burning voltage under varied content of $\Delta^1O_2$ will be described by the relationships derived in [4]; however, an influence of gas temperature on the parameter $(E/p)_{cr}$ in working mixtures of RP IOLs has not been studied yet. It was also shown [8, 9] that an increase in temperature of the gas mixtures comprising the strongly electro-negative component $SF_6$ leads to a higher rate of electron attachment to vibrationally excited molecules $SF_6$ and, consequently, to greater values of $(E/p)_{cr}$. By analogy, one may expect that in standard mixtures of RP COILs with a strongly electro-negative component (iodide) the parameter $(E/p)_{cr}$ will also increase at a higher temperature, which will be accompanied by corresponding variations in the SVD voltage and current.

In this work, we study the influence of gas temperature on SVD characteristics in working mixtures of COILs. The main reasons for measurements described below are the experimentally observed and considered [5] effects of a monotonic decrease in the discharge current and an increase in the voltage during RP COIL operation (operation for up to 1 min at a pulse repetition rate of 20 Hz). The influence of the mixture temperature on the discharge voltage and current is one possible interpretation of the variations in discharge characteristics observed experimentally. Reasons for mixture heating (if the heating really occurs) are not presently clear.

The scheme of the experimental setup is shown in Fig. 1. The SVD burned in the needle (cathode) – plane (anode) geometry at an interelectrode separation $d$ = 5 cm. A capacitor $C$ = 8 nF discharged to the gap through an inductance $L$ = 3.2 μH. The electrodes were placed into an airtight quartz tube of diameter 5 cm filled with a mixture of gases. The study was conducted in the gas mixtures $C_2H_5I$ : air =

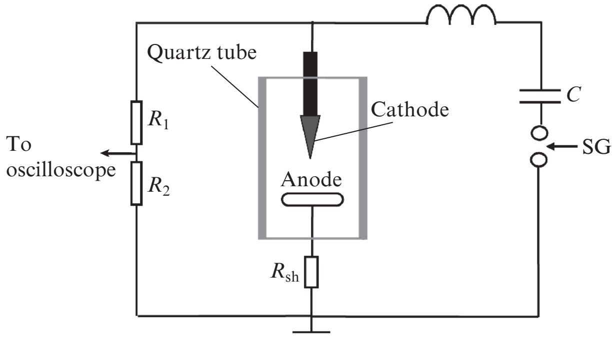

**Figure 1.** Experimental setup: (SG) spark gap; ($R_1$, $R_2$) voltage divider; ($R_{sh}$) current shunt; $C$ = 8 nF; $L$ = 3.2 μH.

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1 : 36 – 1 : 10 at a total pressure of 12 Torr (at a temperature of 22 °C). These gas mixtures imitated the working mixture of RP COILs. Preliminary experiments with the setup described in [5] showed that a substitution of singlet oxygen $\Delta^1O_2$ in the mixture for unexcited oxygen insignificantly affects main characteristics of the SVD except for certain changes in current and voltage amplitudes, whereas the stability and uniformity of the SVD remain constant. Hence, one may expect that the modelling of temperature influence on SVD characteristics in the mixture of iodide with air is adequate from the viewpoint of such an influence in real mixtures of RP COILs.

A capacitor charge voltage in the scheme of Fig. 1 varied in the limits 6 – 10 kV. An electrical breakdown of the gap was initiated by a spark from outside of the quartz chamber, which reduced jitter in the instance of the breakdown to ±10 ns. Note that a minimal spread in the breakdown time is very important for reproducibility of discharge characteristics from pulse to pulse under the conditions of relatively low values of capacitance and charge voltage. The spark started burning simultaneously with a trigger pulse supplied to the controlled spark gap. The current of the SVD and the voltage across the gap were measured by a calibrated shunt and a voltage divider, respectively. The discharge chamber was isolated from a vacuum tract after mixture puffing and then it was heated by hot air flow (to a maximal temperature of 150 °C). A temperature variation was controlled by the corresponding change of pressure. It was assumed that heating of chamber walls to 100 °C does not lead to noticeable dissociation of mixture components.

Preliminary experiments showed that at a low iodide content in the mixture and at temperatures close to room temperatures the voltage of SVD burning and the discharge current are close to the burning voltage and current in air at the same pressure. At a maximal current the values of parameter $E/p$ obtained with neglecting the cathode drop in air and in the gas mixture $C_2H_5I : \text{air} = 1 : 36$ at a temperature of 22 °C are, respectively, 28.1 and 28.5 kV $\text{cm}^{-1}$ $\text{atm}^{-1}$. In this case, the cathode drop cannot be found from the dependences of voltage across plasma $U$ on $pd$ at a maximal current as it was done in [8] because of the large contribution of electron – ion recombination into electron losses in plasma. Hence, at room temperature, the discharge characteristics in mixtures with a low content of a strongly electro-negative component are mainly determined by the characteristics of air, though at the content of iodide in the mixture exceeding 10% the increase in the parameter $E/p$ due to electron attachment to the molecules of a strongly electro-negative gas becomes noticeable (at the same pressure and temperature, the parameter $E/p$ is above 29.4 kV $\text{cm}^{-1}$ $\text{atm}^{-1}$).

The situation changes radically in heating the mixture. In all the mixtures studied, the discharge burning voltage increased and the discharge current decreased at elevated temperatures. The example oscillograms of the SVD voltage and current in the mixture $C_2H_5I : \text{air} = 1 : 36$ with an initial pressure $p = 12$ Torr (at a temperature of 22 °C) recorded at room temperature and under heating the mixture to 96 °C are presented in Fig. 2. From Fig. 2 one can see that already relatively weak heating of the mixture leads to a noticeable fall in the discharge current (by ~12%) and to a concurrent increase in the voltage at current maximum by ~22%, whereas a similar heating of air affects neither voltage nor current. A distinction in the relative changes of current and voltage under heating in this case is explained by the fact that in the mixtures, in which the electron losses in SVD plasma are to a high degree determined by the contribution of electron – ion recombination (the rate of electron losses is $\beta n_e^2$, where $\beta$ is the coefficient of electron – ion recombination and $n_e$ is the electron concentration), the position of the maximal current relative to the voltage oscillogram depends on $n_e$ and, hence, on the discharge current itself. A noticeable increase in the SVD burning voltage under a relatively low temperature elevation is, seemingly, related to higher electron losses in their attachment to vibrationally excited molecules of iodide. This increase exceeds the fall of recombination losses of electrons caused by the temperature dependence of coefficient of recombination: $\beta \propto T^{-1}$ [10], where $T$ is the temperature in Kelvin. In cooling the mixture to room temperature the current and voltage return to their previous values. It is interesting that the influence of temperature on SVD characteristics weakens at a higher content of strongly electro-negative gas in the mixture. For example, in heating the mixture $C_2H_5I : \text{air} = 1 : 10$ with the initial pressure of 12 Torr to 100 °C, the amplitude of the discharge current reduced by at most 3% – 4%.

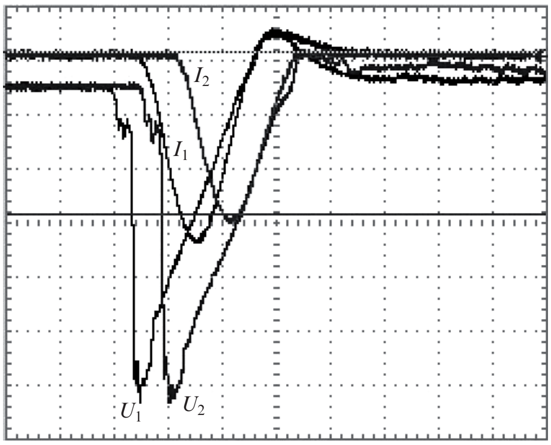

**Figure 2.** Oscillograms of voltage and current in the SVD in the gas mixture $C_2H_5I : \text{air} = 1 : 36$ with a total pressure $p = 12$ Torr at temperatures of 22 °C ($U1$, $I_1$) and 95 °C ($U_2$, $I_2$). The voltage scale is 1.04 kV $\text{div}^{-1}$, the current scale is 68 A $\text{div}^{-1}$, and the time scale is 250 ns $\text{div}^{-1}$.

The distinct influence of heating on discharge characteristics of mixtures with a low and high content of iodide observed experimentally can be qualitatively interpreted as follows. At a low content of iodide, the distribution of electrons over energy is mainly determined by their collisions with molecules of a buffer gas, in our case $N_2$. The voltage increase in this case may be exclusively caused by a higher rate of electron attachment (increased electron losses) to iodide molecules, due to a thermal excitation of vibrational states of iodide, because the state of $N_2$ molecules under a temperature increase by 100K remains actually undisturbed. At a considerable content of iodide in the mixture, the influence of this component mainly leads to the deformation of the energy spectrum of free electrons due to additional losses of electron energy in inelastic collisions with molecules. On this background, the weak raise of electron losses due to their attachment to thermally excited iodide molecules is hardly distinguished, which, actually is directly observed in experiments.

Thus, in the present work it was established that the gas temperature may noticeably affect the electrical characteristics of the SVD in working mixtures of RP COILs, especially in the case of a low iodide content in the mixture. The question as to which processes may heat the mixture is still open. Probably, it may be relaxation of singlet oxygen in its interaction with water directly at the output from the reactor.

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