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New Circulation System of Laser Gas Mixtures

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Abstract

The electrohydrodynamic flow in air, being formed at issue of ions from plasma of the high-frequency barrier discharge is investigated. It is shown that velocity of a flow is proportional to intensity of electric field between the emitter and a collector of ions. All solid-state pulse generator with voltage of U_f = 0-12 kV and pulse repetition rate of f = 10-25 kHz is applied to feed the plasma emitter. It is experimentally established that the increase in high voltage and frequency of the plasma emitter feeding leads to increase velocity of a gas flow. The circulation system with a gas flow rate more than 15 L $s^{-1}$and velocity more than 1.6 m s^{-1} was proposed for electric-discharge lasers.

Introduction

The Electric-discharge lasers are used extensively in industry, medicine, aerospace field and scientific researches. One of an important part of electric-discharge lasers is the circulation system for gas mixtures. Traditionally the formation of speed gas medium is carried out by mechanical fans with rotating elements. Nevertheless, mechanical fans have a number of disadvantages, such as size, weight, form-factor, vibration, noise and so on. They are caused by elements rotating at very high speed.

Electric discharge circulation system is another way to form the gas flow. It is based on “ionic wind” effect. Fig. 1 shows the operating principle of such system. Ions move from HV corona electrode to collector electrode under the action of electric field of corona discharge. The ionic wind forms as a result of momentum transfer from ions to neutral gas molecules. There are no moving parts in the construction of this system. Its construction is fairly simple and compact [1, 2]. However corona discharge has limit value of gas flow up to 3 L s^{-1} [2]. This fact restricts the application of this system in high-power lasers.

We proposed the way for forming an electrohydrodynamic gas flow (EHD-flow) by periodic barrier discharge distributed across the dielectric surface instead the corona discharge [3, 4]. In this case the discharge area may exceed 10^3 cm^2. The proposed approach is void of fundamental restrictions on the gas flow rate, which opens up the way to the development of high-power electric circulation systems.

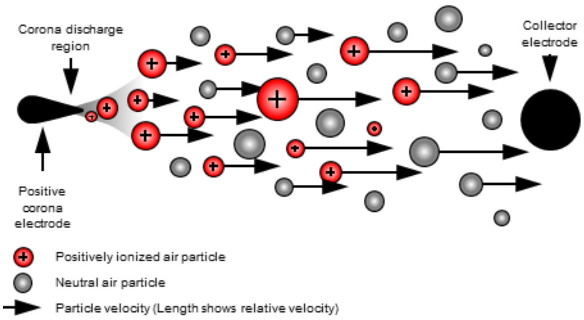

Figure 1. Scheme of EHD flow formation

The aim of our work is to investigate the feasibility of producing electrohydrodynamic flow rates higher than 10 L s^{-1} for the circulation of gas media in electric-discharge lasers.

Description of experimental setup

In our experiments use was made of the setup presented in Fig. 2. The function of charged particle source was fulfilled by the plasma emitter (PE) with a high-frequency barrier discharge induced on it dielectric surface. Plasma emitter has tubular construction with one ore several parallel tubes. The PE consisted of a ceramics dielectric tube of 30-cm long (*1*) (Al2O3) 5 mm in radius. A copper tube (*2*) was inserted inside ceramics tube, which served as the inner electrode. A copper gutter of 20-cm-long (*3*) was the outer electrode. A copper wire (*4*) was coiled around the dielectric tube and the copper gutter, the coil pitch was equal to 5 mm.

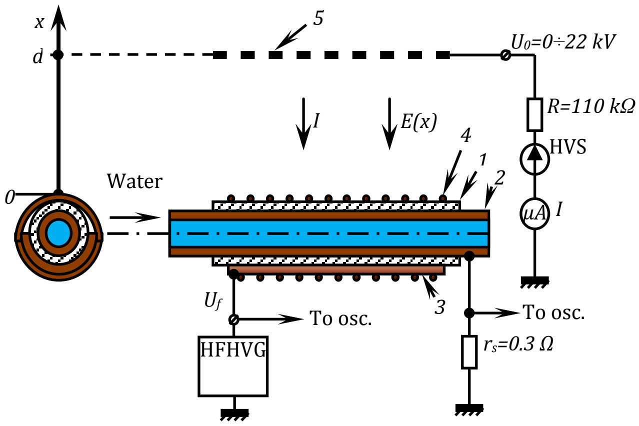

Figure 2. Scheme of experimental setup: 1 – dielectric Al2O3 ceramic tube; 2 – copper tube (inner electrode); 3 – copper gutter (outer electrode); 4 – copper wire; 5 – metal grid with transparence of σ = 0,7; HVS – high voltage source; HFHVG – high frequency high voltage generator.

To feed the plasma emitter, use was made of a specially developed high-frequency high-voltage pulse generator (HFHVPG) [5]. Formed at the generator output were rectangular pulses of positive polarity with a variable voltage amplitude (U_f = 0 – 12 kV), repetition rate f = 10 – 25 kHz. When an alternating voltage was applied to the electrodes of the plasma emitter a barrier discharge plasma layer take place on the outer surface of the dielectric tube.

Above the PE was a metal grid (*5*), which served as an ion beam collector. The separation d between the collector and the emitter was varied. A constant voltage U_0 = 0 – 22 kV of positive polarity from a high-voltage source (HVS) was applied to the grid. Electrons were extracted from the barrier discharge plasma under the action of external field $E(x)$ and formed negative ions by way of three-body attachment to oxygen molecules of air. The ions motion towards the grid produced the EHD-flow (*6*).

Calculated EHD- flow characteristics

To analyze experiments, we give several computational characteristics of the EHD-flow. A one-dimensional model describing the ion beam drifting in the external electric field – between a plane-parallel emitter and an ion collector has been proposed by us [3, 4]. The calculated dependence of the ion current I on the collector voltage U_0 is described by the expression

$$I = S \cdot j = \frac{9}{8} \frac{S \cdot \mu \cdot \varepsilon_0 \cdot U_0^2}{d^3} \qquad (1)$$

where S is the effective area of the ion emitter; d is the collector – emitter separation; μ is the ion mobility and ε_0 is the electric constant.

The expression for velocity V of the gas flow was obtained from this model too.

$$V = \sqrt{\frac{9}{8} \frac{\varepsilon_0}{\rho}} \cdot E_0$$

where $E_0 = U_0/d$ is the average field intensity in the interelectrode gap between an emitter-collector and ρ is the gas density in the gap.

Experimental results

Experimental investigations of electrohydrodynamic flow were curried out in the ambient air. Fig. 3 (a, b) displays the experimental dependences of the: (a) - average ion beam current I on the collector voltage U_0 as well as (b) - velocity V of the gas flow on value $E_0 = U_0/d$ for different d. It can be see the experimental dependences are agree satisfactorily with calculated data.

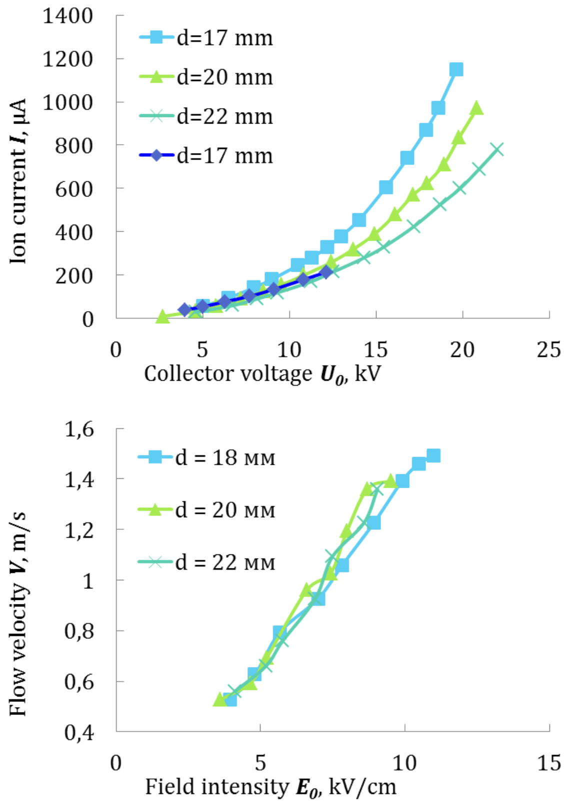

Figure 3. Dependences of ion current I on the collector voltage U_0 for different values of d for the device with two tubes. U_f = 9 kV, f = 30 kHz (a) and dependences of air flow velocity V on average electric field $E_0 = U_0/d$ (b).

Dependences of air flow velocity above the tube on grid voltage U_0 at different values of U_f and f of

HFHVPG are presented in Fig 4. It is evident that the magnitude of V also rises with increasing U_0, U_f, and f. The profiles of the air flow velocity distribution in the plane perpendicular to the gas flow for the case of two PE tubes are plotted in Fig. 5.

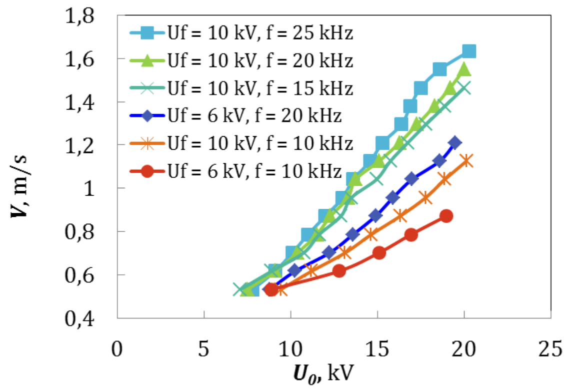

Figure 4. Dependence of air flow velocity above the tube on grid voltage U_0 at different values of U_f and f.

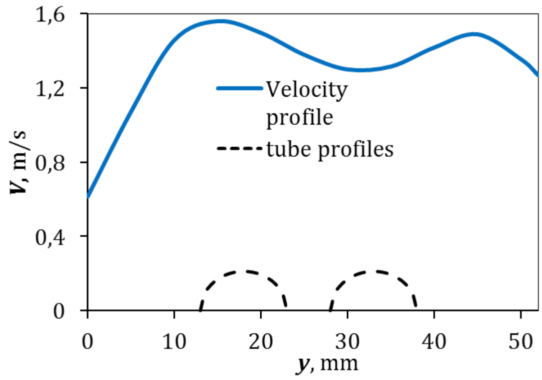

Figure 5. Cross profile for distribution of air flow velocity above two discharge tubes d = 17 mm; U_0 = 17 kV; U_f = 9 kV.

It's follows from the results that performance of EHD-flow are considerably lager then ones based on corona discharge and EHD-flow can be applied for gas mixture circulation in lasers.

EHD-device for the circulation of lasers gas mixtures

The most important factor which controls the highest pulse repetition rate of an electric-discharge laser is the velocity V_d of the working gas mixture in the discharge gap of the laser. The circulation velocity in its turn is determined by the gas flow rate provided by the circulation system:

$$W = V_d S_d = V_d hl$$

where S_d is the flow section area; h is the interelectrode gap; and l is the discharge length. We estimate the gas flow rate for an CL-5000 excimer laser [6], which is commercially available from the Russian company OptoSistemy [7]. The cross-section of electric-discharge laser is shown schematically in Fig. 6.

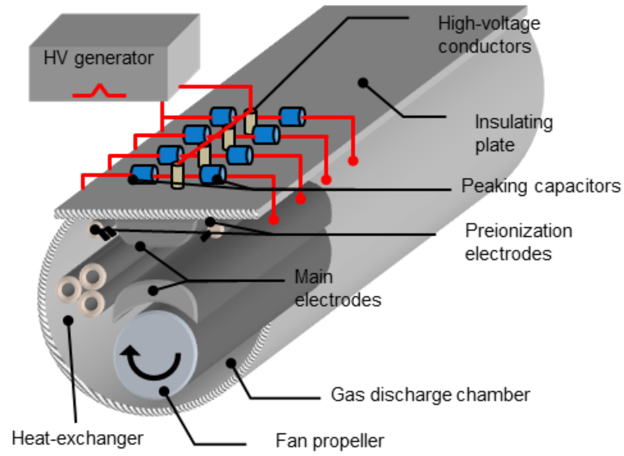

Figure 6. Cross-section of electric-discharge laser.

At the highest pulse repetition rate is equal to 300 Hz the gas flow rate mast be more then 11 L s^{-1} for this laser. We curried out modeling of EHD-flow in excimer gas mixtures by COMSOL Multiphysic program. According to the results of our investigation we determined that to obtain necessary gas flow rate, the PE design should include no less than three tubes similar to that considered above.

Fig. 7 displays a EHD-device with three tubular emitters made of metal ceramics, which is intended for the circulation of gas mixtures in electric-discharge lasers. This device may be built in the discharge chamber instead of fan propeller. In its operation in the air, the flow rate was higher than 15 L s^{-1}, which corresponds to a circulation rate $V_d = W/S_d \approx 5$ m s^{-1} in the discharge gap.

Figure 6. EHD-device for gas mixtures circulation.

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