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The influence of transverse acoustic oscillations on contraction of the glow discharge

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Abstract. The results of investigations of the interaction of longitudinal acoustic waves with electric gas discharge. Describes the phenomenon the formation of vortex flows in the acoustic gas discharge under the influence of a standing acoustic longitudinal waves. The phenomenon of occurrence vortex in the presence of transverse acoustic oscillations of the first tangential mode are analyzed. Presents the rationale of effective influence of the transverse acoustic oscillations on the glow discharge, which leads to the preservation of its diffuse form and, consequently, improve the energy input in the CO_2-laser.

1. Introduction

Laser – one of the most important inventions of the twentieth century. The most powerful lasers, continuous action, at the beginning of the twenty-first century, are CO_2-lasers. In addition to high output power CO_2-lasers have great efficiency up to 20%, and can effectively work in a pulsed mode. These features are responsible for CO_2-lasers diversity of applications: physical research, technological processes, location and communications.

Increased power deposited in the active medium of a CO_2-laser leads to the pinching of the positive column, the contraction of electrical gas discharge. When the contraction of the discharge spatial shape of the electron density distribution along the radius of the tube on the modified parabolic bell [1], there is a strong radial gradient of the gas temperature and the current density on the axis of the positive column gas temperature increases. Such discharge parameters do not meet the necessary conditions for work carbon dioxide laser with high specific power generation and lead to a complete cessation of laser generation. Discontraction discharge accompanied by the opposite phenomenon. Overcoming this kind of instability of the discharge is the main and most difficult problem in creating high-power lasers.

Conducted intensive research of the discharge in a longitudinal gas flow in order to overcome contraction of the discharge gap by increasing the gas pressure [2], to ascertain the possibility of withdrawal of heat from the tube, electrical shock emitted in the discharge area, and create a uniform uncontracted positive column at high pressures.

2. The influence of longitudinal acoustic oscillations on contraction of the glow discharge

Get discontraction discharge uniform at high pressures succeeded with the help of intense sound wave directed along the positive column. Experiments were carried out at the first resonant frequency of longitudinal acoustic oscillations [3]. When implementing the acoustic oscillations in the discharge

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gap CO_2-laser heat can be intensified, thereby reducing output time of heat from the discharge, which would raise the power density, and hence the density of the energy output with help radiation.

From the theoretical analysis of the processes that caused discontraction gas discharge sound wave follows that acoustic field inhomogeneity in the discharge tube there are, firstly, due to the boundary layer near the wall where the velocity is reduced from the value in the acoustic wave in the middle of the tube to zero at the wall of the tube, and second, due to the strong temperature gradient along the radius of the tube.

In the presence of solid walls, the acoustic field non-uniformity and the existence of the transverse profile of a standing wave arises steady vortex flow called acoustic flow [4], which reinforces transport processes along the radius of the tube. This causes an increase in the effective thermal conductivity of the plasma, leading to a decrease gas temperature increase of the diffusion losses of the charged particles on the wall and discontracted positive column.

For the existence of the phenomenon of acoustic flow is necessary that the size of the heterogeneity of the acoustic field was much larger than the thickness of the boundary layer. Thus, only the strong temperature non-uniformity across the radius of the tube is responsible for the occurrence of acoustic flows in a longitudinal standing wave affecting the transport processes [3].

From the foregoing follows that the discontraction discharge leads to equalization temperature gas on radius of the tube and, consequently, to reduce the degree of influence of the temperature non-uniformity on the acoustic excitation of the vortices.

3. The influence of transverse acoustic oscillations on contraction of the glow discharge

Longitudinal standing wave of acoustic oscillation is characterized by a specific location alternating maxima (anti-nodes) and minima (nodes) of the amplitude, while in the case of transverse acoustic oscillations set pattern is the same for each section a discharge chamber, where discharge light, thereby creating a uniform distribution of excited gas along the length of the tube. Research conducted on experimental stand [5] confirm the findings.

Experimental stand consisted of a molybdenum tube with an internal diameter of 9.5 cm and length 21 cm, closed at both ends faces of various shapes (conical, and hopping cross section) Electrode annular shaped with cross-sectional diameter of 0.4 cm and a DC power source. For creating sound waves used electrodynamic transducer, which was placed on the cylindrical wall of the end-hopping cross-section. In electrodynamic transducers was served a sinusoidal electrical signal with help generator. For the control parameters of the sound waves using a microphone which is able to move freely throughout inner surface of the tube, the signal from the microphone is fed to an oscilloscope. Reduced pressure created by the vacuum pump.

At realization the transverse acoustic oscillations in the tube should be expected discontraction at higher pressures and powers invested in discharge than in the case of longitudinal acoustic oscillations. Since by past the mechanism excitation of acoustic vortices, due to, the strong temperature non-uniformity, will be implemented transverse profile of a standing wave, which is an additional reason for the formation of acoustic vortices which carry the plasma to the radial direction and ensure the intensification of heat transfer along the radius of the tube.

Thus the velocity potential for transverse modes of acoustic oscillations has the form

$$\varphi = J_m\left(k_{mn}r\right)\cos\left(k_{mn}t \pm m\theta\right)e^{\varepsilon t}, \tag{1}$$

where J_m – Bessel function of m-th order, k_{mn} – wave number, ε – oscillation increment. Then the expression for the velocity of the transverse acoustic oscillations is

$$\boldsymbol{u} = -\frac{1}{k_{mn}}\frac{dJ_m\left(k_{mn}r\right)}{dr}\sin\left(k_{mn}t \pm m\theta\right)e^{\varepsilon t}\boldsymbol{e}_r \pm \frac{m}{k_{mn}}\frac{J_m\left(k_{mn}r\right)}{r}\cos\left(k_{mn}t \pm m\theta\right)e^{\varepsilon t}\boldsymbol{e}_\theta, \tag{2}$$

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where $\boldsymbol{e}_r$ and $\boldsymbol{e}_\theta$ – the unit vectors, respectively, radial and tangential directions.

This is a acoustic solution for the transverse modes in a closed cylinder, which is a conservative system analogous to the discharge tube. Here the upper sign takes into account the growth of the amplitude of the time, the lower sign – decrease. Nonlinear generation of vortex flows is not oscillatory mechanism is mechanism a nonlinear stabilization of amplitudes of unstable oscillation.

Using the acoustic solution (2) to calculate the the stationary flows in the finite-amplitude acoustic waves. The mass flow in the fixed-point number of a closed cylinder

$$\boldsymbol{\mu} = \rho \boldsymbol{v}, \tag{3}$$

wherein ρ and $\boldsymbol{v}$ density and gas velocity at a fixed point, respectively. Represent parameters ρ and $\boldsymbol{v}$ as

$$\rho = \rho_0 + \rho, \ \boldsymbol{v} = \boldsymbol{v}_0 + \boldsymbol{v}_1, \tag{4}$$

ρ_1, $\boldsymbol{v}_1$ – acoustic components of density and gas velocity, respectively. For the mass flow with oscillations have

$$\boldsymbol{\mu} = \rho_0 \left(1+\eta\right)\left(\boldsymbol{v}_0 + \boldsymbol{v}_1\right) = \rho_0 \boldsymbol{v}_0 + \rho_0 \eta \boldsymbol{v}_0 + \rho_0 \boldsymbol{v}_1 + \rho_0 \eta \boldsymbol{v}_1 . \tag{5}$$

Here $\eta = \rho_1 / \rho_0$ – dimensionless density. The first term of the expansion defines the average mass flow, terms of first order give corrections to momentum flux due to wave motion and because of the density fluctuations. Not the oscillating part of the secondary flow is only the second order term $\rho_0 \eta \boldsymbol{v}_1$. After averaging over the period of this term acoustic (with ε = 0) oscillations for tangential flow have the following result

$$\eta \boldsymbol{u} = \pm \frac{m J_m^2 \left(k_{mn} r\right)}{2 k_{mn} r} \boldsymbol{e}_\theta \tag{6}$$

The upper sign corresponds to the tangential wave propagating in a clockwise direction, the lower sign – wave propagating counterclockwise. The distribution of secondary the mass flow to the radius of the first tangential mode has a maximum radius at a distance of a quarter of the wall [6]. This result means that the acoustic waves create a steady transfer tangential pulse relative to the cylinder axis and as a consequence, gas transfer occurs.

4. Conclusions

That is, discontraction effect of the gas discharge sound wave can be enhanced by initiating acoustic oscillations with transverse velocity profile in the standing wave, thereby increasing intensification of heat transfer in the radial direction, and consequently, increasing the upper limit of energy input to the discharge, while maintaining them diffuse form that will to increase the power of the gas laser. This can be achieved by exciting in a discharge chamber transverse acoustic oscillations.

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