Combined method of stabilization of the glow discharge in gas flow

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Abstract. Many applications of the glow discharge need the discharge power and gas pressure grow up. As usual this cause the appearance of discharge instabilities which violate the normal glow mode. Here the combination of two methods of stabilization of the glow discharge with gas flow is considered.

1. Introduction

Volumetric glow discharge can be effectively used for pumping active medium of the optical lasers with higher power, but to achieve it, it is necessary to create the conditions for homogeneous volume pumping of the active medium. To increase the limiting characteristics of the stable volumetric discharge gas pumping is used, including the supersonic one.

In most cases in practical implementation of glow discharge to make an influence on the surface the glow discharge with a transverse direction of the gas flow is often used. In this case it is possible to use camera with the variety of geometry, to imply different ways of preionisation, etc. When arranging the glow discharge in a transverse direction of gas flow sectionalized cooled cathode blocks are widely employed. Cathode sections of cathode blocks are usually separated from each other with dielectric layers.

In most cases in practical implementation of glow discharge it is necessary to provide the stable homogeneous volumetric burning mode of the discharge at high current values and specific energy input. The increase of the characteristics of the discharge is limited because of the discharge instability development, firstly – ionization-overheating instability which causes discharge contraction.

To achieve stable values of electric and thermal characteristics of a glow discharge [1-3], effective methods are applied to the cathode region of a glow discharge. This is due to the fact that the transition of the discharge to the contracted state is accompanied by compression of the cathode spot.

For glow discharge it is normal that at low pressures cathode spot occupies much more place on the cathode, what corresponds to the Gehl law for the normal cathode current density $j/N^2 = \text{const}$, where $j$ – current density on the cathode, $N$ – concentration of neutral gas particles. With the increase of gas pressure cathode spot decreases (inverse square law) quite strongly. However glow discharge positive column occupies rather big space of discharge chamber. As it is known cathode heat dissipation is rather big, so that it might be the reason for emergence and development of the thermal instability on the cathode. Consequently there are limitations for maximum possible currents of stable volumetric glow discharge, at the same time homogeneous pumping of active laser medium decreases significantly.

There are a number of methods of glow discharge stabilizing, efficiency of which depends on several factors. The general principle for all these methods of stabilization is not to allow conditions...
for instabilities. To achieve it swamping resistors, gas flow swirl, different ways of preionisation, cathode sectioning, effects of spinning magnetic field etc. are used.

The ways to chip away at instability development can be divided into two types:
- effects, leveling discharge characteristics according to the chamber capacity, for example preionisation and gas flow swirl
- effects of speeding the processes of instability development, for example effect of spinning magnetic field.

2. Passive stabilization

In this research we consider the way combining the two types of stabilizing effect. As it was mentioned above, the glow discharge in transverse gas flow is considered. Here we use a cathode block, consisting of not very big copper sections, separated from each other dielectrically with cooling distilled water. On the upper surface of the cathode plates the layer of intermissive dielectric enamel coating was put [4]. The basic rectangular cell of cathode uninsulated section was the size of 3x4 mm$^2$.

Anode is a copper plate.

At rather low values of pressure, gas flow and electric current, the discharge glows in a diffused mode and fills in with itself the whole surface of the cathode sections. While increasing the voltage on the discharge or increasing the pressure, the discharge contracts to a spot on the cathode, usually it happens downstream, and then at a further increasing of discharge current, it continues contracting to a point on the cathode, where there are preferential conditions for discharge burning.

In most cases the conditions for the development of ionized-overheated instability are realized nearby the cathode, where the processes of intensive ionization and significant heat release occur. Thus, the stabilizing effect in the examined approach will be caused by currents control, flowing through the cathode sections.

On the one hand there is an efficient stretching of a cathode spot by putting on it an intermissive dielectric coating. It makes the cathode spot to spread along the cathode section. Consequently the cathode heat dissipation is distributed along the cathode section more uniformly. Therefore the water cooling can effectively draw off the heat dissipating in the near cathode space. Thus, the conditions for the glow discharge instability growth near cathode surface become less realizable. So the higher upper limit values of the discharge current without contraction can be reached.

On the other hand an advanced control action is taken on the electrical potentials of the cathode sections to prevent the compression of the cathode spot, followed by contraction of the discharge.

3. Active stabilization

Stretching of the cathode spot along the surface of the cathode section prevents compression of the cathode spot within one section. And the control of the potentials of the sections makes it possible to further increase the limiting values of currents, voltages and pressures while maintaining a stable diffuse discharge regime.

The characteristic time for the development of the ionization-overheating instability is of the order of 10-3 s. Consequently, the time for which the stabilizing effect must eliminate the conditions for the development of the ionization-overheating instability should have a significantly lower value.

The essence of the method is to continuously monitor the dynamics of changes in the values of the currents through individual cathode sections. With a stable diffuse burning mode of a glow discharge, the law of the constancy of the current density at the cathode is usually satisfied. If the stable burning regime is violated, and a transition to the contracted combustion form of the discharge occurs, this will be accompanied by the appearance of an increasing uneven distribution of the current among the cathode sections. Through some sections the current will increase, and through the remaining sections the current values will decrease. Timely determining those sections through which large currents begin
to flow, it is necessary to increase their ballast resistances. At the same time, it is necessary to reduce the resistance of neighboring sections, the currents through which begin to decrease. Thus, the cathode spot will be forced to move, stretching across the cathode, and the development of instability will be prevented [5].

Obviously, because of the rather small characteristic time of development of the ionization-overheating instability (10-3 s), the stabilization system must be automated. It should implement the next functions:
- measurement of discharge parameters,
- calculation of the parameters change rate,
- comparison of the parameters with previous values for a given cathode section,
- comparison of the parameters with the values of adjacent cathode sections,
- selection of the control algorithm,
- formation of the control action,
- evaluation of the result of the control action,
- protection from approaching critical conditions of the discharge,
- protective discharge shutdown.

The modern development of digital information and measuring tools makes it possible to implement such a system of dynamic stabilization of a glow discharge. In general, the stabilization system consists of a block of measuring resistors, a matching circuit, a commutator with a multiplexer, an analog-to-digital converter (ADC), a computer or microcontroller, a cathode section potential control unit.

The current through each section is determined by the voltage drop across the measuring resistors with low resistance. After passing the matching circuit, the converted signal from each section is serially connected via a switch to the ADC. After that, the voltage (current) data of each section is fed to the microcomputer for processing. The data is processed in the microcomputer. The values of the currents of adjacent sections and the dynamics of the change in the currents in all sections are compared. An analysis of these changes is performed depending on the change in the discharge burning conditions: the values of the pressure distribution in the discharge chamber, the gas flow, voltages and currents. After processing the data, a control signal is generated, which is fed to the cathode section potential management system. The cathode section potential control circuit consists of a digital-to-analog converter, a demultiplexer and switching elements whose resistance can vary depending on the control signal.

The hardware of the stabilization system is supplemented with appropriate software. The program manages the processes of measuring the parameters of the experimental setup, transferring measurement results to a microcomputer, analyzing the flow of experimental data, generating control commands, monitoring execution, and so on. A special role of the software is to provide a dynamically maintained unstable discharge equilibrium near the critical (maximal) current values through the cathode sections.

On the one hand, the stabilization system should ensure a stable diffuse discharge burning regime. On the other hand, it should not be possible to reduce the currents to the minimum values due to excessive regulation. Depending on the operator's settings, the system can support discharge burning in different modes in relation to proximity to the critical mode. The use of the preionization system built into the experimental setup greatly extends the range of regulation of the limiting currents, the magnitude of which is limited by the efficiency of the electrode cooling system.

4. Conclusion.

By influencing the cathode discharge region, it is possible to increase the homogeneity of the distribution of the average discharge characteristics over the entire volume of the discharge region and to increase the discharge stability limits.
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