MICROWAVE DISCHARGE AS A SOURCE OF LIGHT

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We try to analyze the ways to optimize microwave discharges in a microwave light source. The problem here is that as the discharge starts glowing, electrodynamic properties of the plasma being the load for the microwave source change significantly. During this, the characteristics of the light radiation from the plasma and efficiency of using the microwave energy are far from optimal. We propose a way to solve this problem, which is based on creating a multi-resonance electrodynamic system tuning automatically as the value of the plasma load changes, thus providing reasonably good coupling in all regimes of operation of the lamp.

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INTRODUCTION

Recently, the interest has appeared for creating highly efficient sources of visible light, which are based on microwave discharges in vapors of sulfur and other substances [1]. Among the merits of such light sources are sufficiently high luminous efficiency, low level of IR and UV components in their radiation, quality color rendition, long lifetime. However, there is a basic difficulty in realizing such light sources, which is associated with the dynamic character of the plasma load. The problem is that the value of the load being (the plasma of the gas discharge in the tube) changes as the lamp starts glowing. Whereas this load is comparatively small before the discharge is ignited and at the initial stage of lamp glowing, it changes as the lamp comes up to the stationary operation regime, and achieves some value which differs from the initial one significantly. In a simplest single-mode electrodynamic system the inevitable situations are either a high reflection level at the beginning of lamp glowing, or a not exactly matched regime of magnetron operation at the stationary phase of the discharge. This paper analyses this problem and proposes a way to solve it, which is based on creating a multi-resonance electrodynamic system that tunes automatically as the value of the plasma load changes, thus providing sufficiently good coupling in all regimes of lamp operation.

DYNAMIC CHARACTER OF THE PLASMA LOAD

A characteristic feature of microwave light sources is the non-stationary character of the load being the plasma of the lamp gas discharge. This feature is associated with the fact that after the gas in the tube is broken down and the discharge starts to glow, the impedance of the load changes drastically. Further the gas is heated, the working substance (sulfur, selenium or metal halogens) is evaporated, and the density of charged particles grows, which also changes the load impedance [1]. It is especially important to take into account variations of the pressure in the tube when pulsed microwave sources are used, since at the initial stage the gas temperature is low, and after the end of the microwave pulse the plasma degenerates in a short time. Hence, it is necessary to breakdown the gas again at each consequent pulse, but at a higher density of neutral particles already. However, increasing density of neutrals makes the frequency of electron-neutral collisions higher, which, in its turn, results in the increase in the intensity of the electric field required for a secondary gas breakdown.

Where as at the stage of discharge ignition and initial gas breakdown the value of the load is not greate, and the determining factor is the losses in the resonator walls, later, as the lamp warms up and comes up to the stationary operation regime, the share of the power absorbed in the discharge becomes greater, which is directly the objective and a necessary requirement for high luminous efficiency of the lamp.

Coexistence of several lamp operation regimes, which are very different, and the necessity to have a stable transition between them makes it necessary to create such an electrodynamic system, which could change its properties dynamically as the lamp starts glowing and the value of the load changes. Additionally, we have to provide optimal coupling and a stable dynamic transition from the stage of the initial breakdown to the stage of stationary glowing.

We think that the most efficient way is to create a multi-resonance system with the ability to tune dynamically to the changing load. Principal requirements to such a system is the possibility to tune the resonance frequency of the system in the required direction to compensate the variation of the resonance frequency introduced by the changing plasma load, on the one hand, and to change the value of the coupling between the feeder and the resonator, on the other hand.

The electrodynamic system proposed here has three operation regimes, which differ in terms of the value of the coupling between the magnetron and the resonator. The first of them is the initial breakdown in the tube, the second provides a reliable transition to the stationary glowing regime, and the third maintains the regime of lamp operation. Each of these regimes is characterized by the position and width of the resonance band. For example, the ignition regime requires good coupling of the magnetron with an empty (containing no plasma) resonator, and achieving of high field intensity in it. Hence, in this regime it is necessary to produce a high-Q-factor resonance tuned precisely to the magnetron frequency. The main regime of operation requires coupling with the well-absorbing plasma load and, correspondingly, a significantly lower Q-factor and better coupling with the resonator. The transition regime should provide a stable and reliable transition from the ignition regime to the glowing regime, thus it is necessary to provide an intermediate value of the magnetron-resonator coupling, i.e. the resonance should have an intermediate Q-factor.

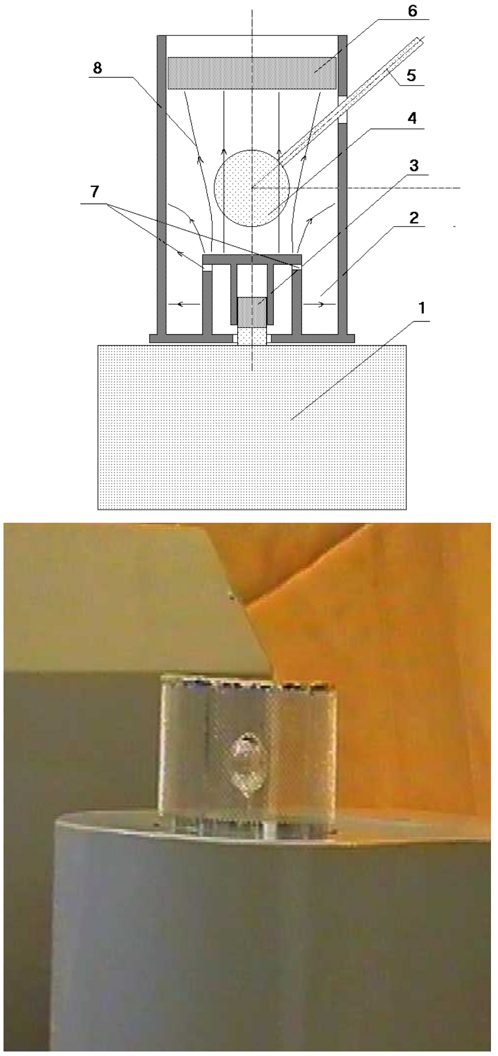
ELECTRODYNAMIC SYSTEM

In terms of its design, such a light source is a quartz tube with the required filling placed in a microwave resonator made partially of a metal grating with high light transparence. The microwaves were generated by a magnetron at the frequency of 2.45 GHz.

Figure 1 shows the scheme of a version of such a microwave light source. The microwaves are generated by a magnetron (1), the antenna of which (3) is placed in a circular waveguide, which is the feeder and via the coupling slit (7) is coupled with a cylindrical resonator (2) with a movable wall (6). The resonator is made partially of a metal grating that is sufficiently transparent for light, but at the same time screens the microwaves. A quartz tube (4) on the axis (5) filled with sulfur or a mixture of metal halogens is placed in the resonator. To provide ignition and evaporation of solid-state admixture, the tube is filled also with an inert gas, e.g. argon under the pressure of 10-20 Torr.

Two polarization-degenerate modes H_{111} and one E_{010} mode of a circular resonator are used as working modes in the proposed electrodynamic system. The latter modes provides a high coefficient of the feeder's coupling with the resonator loaded with a plasma load, which is well-absorbing and, thus, provides good coupling with the magnetron. Figure 1 shows also force lines of the electric field (8) for mode H_{111}. Frequency tuning of the electrodynamic system is performed by selecting the diameter of the cylinder and changing its height. The coupling factor is controlled by changing the depth of the antenna position in the resonator. Thus, the tuning of the electrodynamic system is an iterative procedure.

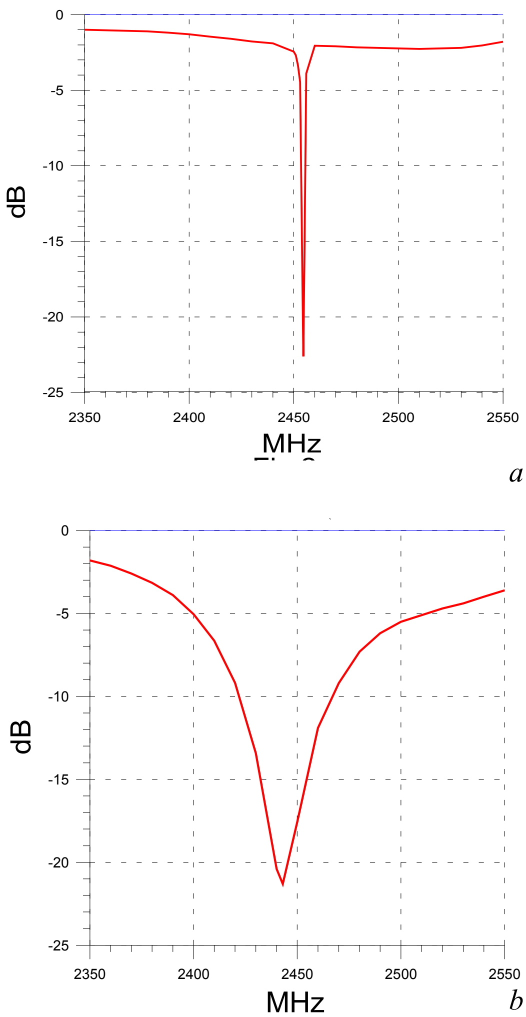
Figures 2a and 2b show frequency dependences of the coefficient of reflection from the resonator for different values of the load placed in the resonator. In the absence of absorption (Fig. 2a) one can see that there is a sharp and deep resonance: a dip in the reflection coefficient. This regime is for the initial gas breakdown.



a

b

Fig. 1:
a) schematic drawing of the microwave light source;
b) photography of the microwave light source; there is a quartz bulb inside of grid resonator



a

b

Fig. 2. Reflection coefficient: a)low absorption;
b) high absorption

The pronounced dip evidences that the value of the magnetron-resonator coupling selected by us is close to the losses in the empty resonator, thus providing, in accord with our idea, the maximum amplitude of the field in the resonator required for the breakdown.

Figure 2b shows a similar frequency dependence of the reflection ratio under the condition of a sufficiently strong absorption caused by introduction of a model load. It is seen that a wide and deep resonance takes place here. In this case we have the regime of operation, in which the magnetron is strongly coupled with the resonator.

Figure 3 presents the photograph of the working microwave light source.

CONCLUSIONS

This paper describes the electrodynamic system of a microwave lamp with a three-mode resonator. The system is designed to provide stable ignition of the discharge in the lamp and the transition to the stationary glowing regime. Optimization of the discharge evolution process and of the plasma load coupling at the stationary stage made it possible to achieve high efficiency, up to 140lm/W.

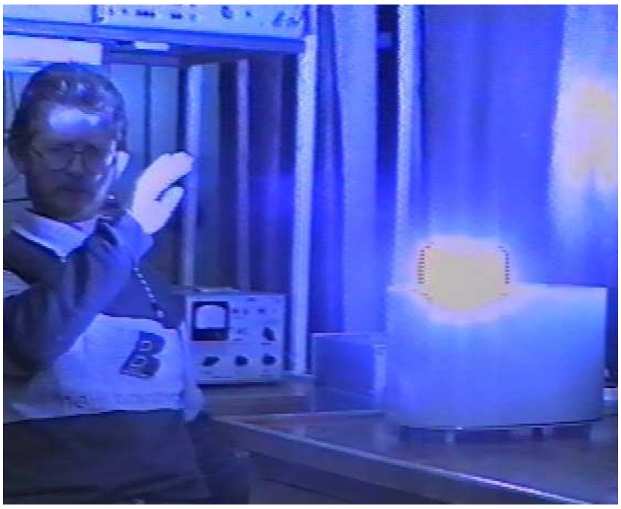


Fig. 3. Working 200 W microwave light source

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МИКРОВОЛНОВОЙ РАЗРЯД КАК ИСТОЧНИК СВЕТА

Ю.Я. Бродский, Н.Ф. Ковалев, А.О. Перминов, С.П. Шлепнев

Проведен анализ путей оптимизации согласования микроволнового разряда в микроволновом источнике света. Проблема связана с тем обстоятельством, что при развитии разряда характер нагрузки меняется существенным образом. При этом происходит рассогласование, и энергия не поступает в разряд. Мы предлагаем путь решения этой проблемы, основанный на использовании многомодовой электродинамической системы, которая автоматически следит за изменением импеданса нагрузки.

МІКРОХВИЛЬОВИЙ РОЗРЯД ЯК ДЖЕРЕЛО СВІТЛА

Ю.Я. Бродський, М.Ф. Ковальов, А.О. Пермінов, С.П. Шлепнєв

Проведено аналіз шляхів оптимізації узгодження мікрохвильового розряду в мікрохвильовому джерелі світла. Проблема зв'язана з тією обставиною, що при розвитку розряду характер навантаження міняється істотно. При цьому відбувається неузгодженість, і енергія не надходить у розряд. Ми пропонуємо шлях рішення цієї проблеми, заснований на використанні багатомодової електродинамічної системи, що автоматично стежить за зміною імпедансу навантаження.