RADIATION OF MULTICOMPONENT GAS-METAL PLASMA OF A PULSED REFLEX DISCHARGE

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Measurements on the radiation flux of gas-metal plasma formed in the medium of igniting gas (gas mixture) and sputtered cathode material in the pulsed reflex discharge were carried out. A spectrometric method was applied to determine the composition of gas-metal plasma formed.

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A reflex discharge, known as a Penning discharge or Phillips discharge is a discharge of an axisymmetric geometry taking place in the crossed electric and magnetic fields [1]. At present, the Penning discharge, realized in many applied and engineering problems, continues to be extensively investigated despite its long history [2, 3].

However, there is a deficiency of experimental data in the investigation of the pulsed reflex discharge, in particular, in the determination of an elemental composition and intensity of plasma radiation, as well as, in the investigation of properties of both gas- and gas-metal multicomponent plasmas, that it very important for determining the energy balance of systems under study [3,4].

The present work is a continuation of previous investigations on the characteristics of multicomponent gas-metal plasma in the pulsed reflex discharge [5,6]. The purpose of the work was to measure the parametric dependences of the plasma optic radiation intensity and comparative analysis of the radiation from gas-metal plasmas having a uniform average density to determine the level of energy loss from the volume in the investigated wavelength range.

Experiments were carried out in the installations described in [5,6]. Gas-metal plasma was formed as a result of the discharge in the working medium composed of H_2, Ar or a gas mixture containing 88,9%Kr-7%Xe-4%N_2-0,1%O_2 and sputtered metallic Ti.

Cathodes were made of a monometallic Ti or a composite material, namely, Cu with Ti deposited by the vacuum-arc method. A discharge chamber was pumped out by means of a diffusion pump with an absorption trap to a pressure of 10^{-6} Torr with subsequent inlet of working gas or gas mixture.

The following diagnostic tools were used: the time dependence of the average plasma density was determined by means of a microwave interferometer at the operating wave length $\lambda = 8$ mm; the time dependence of the plasma radiation intensity in the range of wavelengths λ=180…1100 nm was measured by a photodiode FDUK-13U operating in the photodiode mode, the time constant of the signal rise front was $\tau \sim$ 300 ns; the elemental composition of the formed plasma was determined by the spectroscopic method. The radiation was recorded via the diagnostic window, made of quartz glass KU 1, being at a distance of 220 mm from the plasma boundary. The area of a photo-receiving surface was Ø 2.5mm, the threshold response at λ_{max} $P_{thres.} = 0.4\times10^{-14}$ W/Hz$^{1/2}$. The radiation measurements in the ultraviolet and near infrared spectrum ranges were carried out using the filters: optical glasses UFS-2 in the ultraviolet region and IKS-1 in the infrared region.

The plasma radiation and the average density was carried out with the following discharge parameters: $U_{dis.} = 3.4…3.8$ kV; working gas (mixture) pressure p = $(1.5…8)\times10^{-3}$ Torr; magnetic field duration of 18 ms; maximum magnetic field value in the cross-section of diagnostic means was H_{max} = 4360 Oe; the discharge was initiated with a delay of 2 ms relatively to the magnetic field connection.

Fig.1 presents the time dependences of the average plasma density for the hydrogen-titanium and Kr-Xe-N_2-O_2+ Ti plasmas and for the radiation flux from these plasmas in the different spectrum ranges (see Fig. 1, curves 1-4). Comparison of the given experimental dependences (see Fig. 1, curves 2-4) shows that the main contribution in the total radiation flux belongs to the visible spectrum part (~ 80%).

The measured time of plasma density increase up to $N_p \geq 1.7\times10^{13}$ cm^{-3} was Δt ~ 110 μs for (H_2+Ti) and ~ 80 μs for (Kr-Xe-N_2-O_2+Ti). The time of existence of the plasma layer having the density $N_p \geq 1.7\times10^{13}$ cm^{-3}, recorded by the microwave cutoff was Δt ~ 1 ms for the plasma (H_2+Ti), Δt ~ 1.8 ms (Kr-Xe-N_2-O_2 +Ti). The maximum value of the measured plasma radiation flux in the case of using composite cathodes was 3.7×10^{-4} W (H_2+Ti), 4.4×10^{-4} W (Kr-Xe-N_2-O_2+Ti).

The radiation flux ratio with an equal average density in the given density range for Kr-Xe-N_2-O_2+Ti and H_2+Ti is at the level of 1.1…1.3. The time dependence of the radiation flux from gas-metal plasmas (Ar+Ti and Kr-Xe-N_2-O_2 +Ti) with the use of monometal cathodes is shown in Fig.2. The maximum value of the measured plasma radiation flux was 9.2×10^{-4} W (Ar+Ti), 8.6×10^{-4} W (Kr-Xe-N_2-O_2+Ti).

For measurements of the elemental and charge composition of plasma we used a spectrometer operating in the accumulation mode designed to record an integral spectrum of the radiation emerging from the plasma during the time of its existence. In Figs. 3, a-d given are the results of measurement on the linear spectrum of the plasma formed in the medium of igniting gas H_2, Ar and gas mixture Kr-Xe-N_2-O_2 with the use of monometal cathodes (Fig. 3, a, b) and composite titanium cathodes (Fig. 3, c, d). The use of two types of cathodes in both cases leads to the entry of cathode material (Ti) into the plasma that is confirmed by the spectrometric measurements. The titanium content in the discharge for composite materials determined in [7] is at a level of 40…50%.

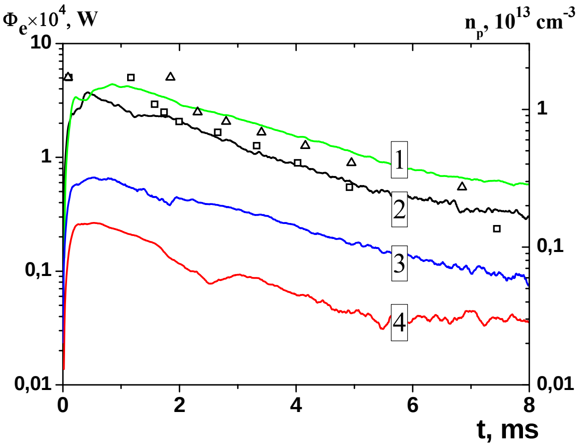

Fig.1. Time dependence of the plasma radiation flux (solid curves), and the average plasma density (points), $U_{dis.}$ = 3,4 kV (composite cathodes). 1– Kr-Xe-N_2-O_2+Ti (Δ), λ=180…1100 nm; H_2+Ti (□): 2 – λ=180…1100 nm, 3 –λ =260…390 nm; 4 – λ=810…1100 nm

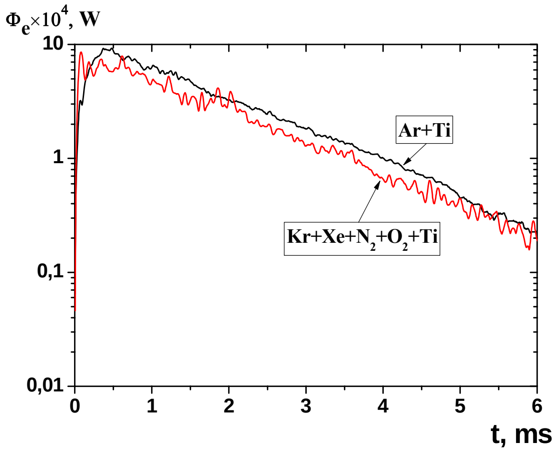

Fig. 2. Time dependence of the plasma radiation flux, $U_{dis.}$ = 3.8 kV (monometal cathodes)

The same value is confirmed by both the volume-mass content and the measurements of cathode material consumption after 3000 discharge pulses. In the formed plasma spectrum, besides igniting gas elements and cathode material, there observed are the lines of the following atoms (ions) and molecules (molecular ions): oxygen, hydrogen, nitrogen, carbon and hydroxyl group OH. Oxygen, nitrogen and water are the traces of the residual atmosphere; hydrogen and carbon are the desorption products from the discharge chamber walls and of the dissociation of diffusion oil cracking fragments. The intensity of impurity lines (nitrogen, carbon et al.) is varying from one pulse series to another that evidences on the initial vacuum condition changing. It is natural that under the influence of particles and radiation on the vacuum surfaces, the composition of the layer adsorbed on the surface are constantly changing, besides the deposited titanium films have high sorption characteristics. Therefore, for estimation of the content of impurities entering into the discharge, let us assume, for initial conditions, the duration of preliminary atmosphere evacuation ~ 10 hours. So, using the basic relations of the gas-kinetic theory of neutral gas particle transfer in the space "vacuum chamber wall-plasma volume" and taking into account the percentage of residual atmosphere components, we estimated by calculation the nitrogen concentration at a level of a percent, and that of carbon and oxygen at a level of several percents.

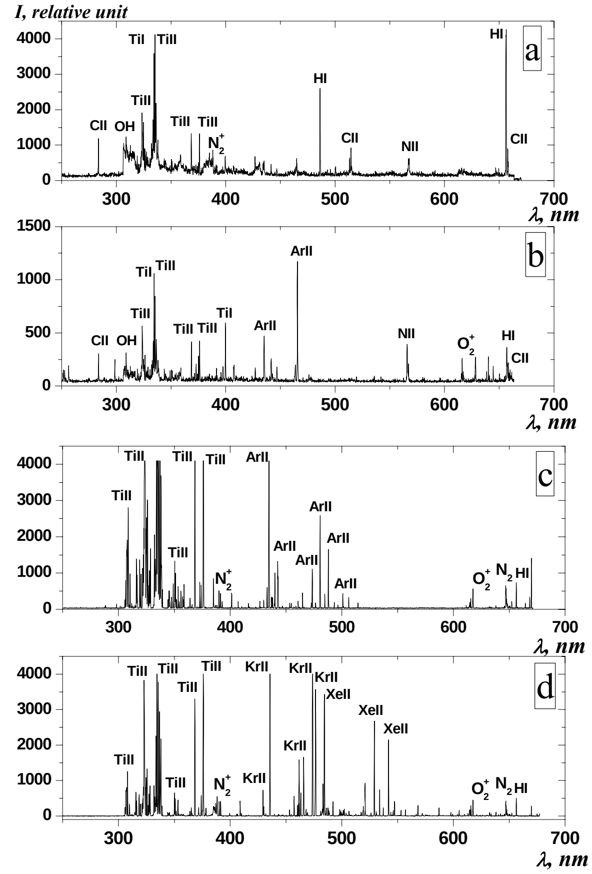

Fig. 3. Spectrogram of the plasma integral linear radiation. a – H_2+Ti; b – Ar+Ti; c – Ar+Ti; d – Kr-Xe-N_2-O_2 +Ti. a, b – composite cathodes; c, d – monometal cathodes

The total power of radiation loss on the Z-charge ions from the plasma volume unit is composed of the linear and photorecombination radiation, bremsstrahlung, and the radiation accompanying the dielectric recombination and charge exchange. The calculated values of the radiation loss power function for pure metals obtained in [8-12] in the frameworks of a stationary ionization equilibrium are presented in Fig. 4. Naturally, that for the multicomponent plasma the radiation loss will be combined of the loss for single elements and their percentage in the plasma. Therefore, we estimate the effective loss power for the multicomponent plasma having the elemental composition similar to that obtained experimentally. The percentage was taken equal to the above estimates as the ratio of the impurity element concentration to the basic element concentration, for example, n(Ti)/n(H). The calculation results are presented in Fig. 5. For the pulsed systems, where the atomic relaxation time $\tau \approx 10^{12}/n_e$ exceeds the plasma life time such an approach is not quite proved, though in the given case the measurement results are in accord with the calculations. In the case of stationary conditions, that in principle is a further step of experimental investigations, the total radiation loss power $P=n_e n_i L_{eff}$ for Ar+Ti+impurities at $n_{Ar}=10^{13}$ cm^{-3} and T_e=20 eV will be

30 W/cm^3, i.e. for the volume of ~ 10^4 cm^3 the total power is 300 kW. So, for the stationary discharge with the same parameters significant powers will be required to create and maintain the mentioned plasma parameters, the density decrease by an order of magnitude will reduce the radiation loss down to 3 kW in the given volumes that is completely acceptable for laboratory facilities.

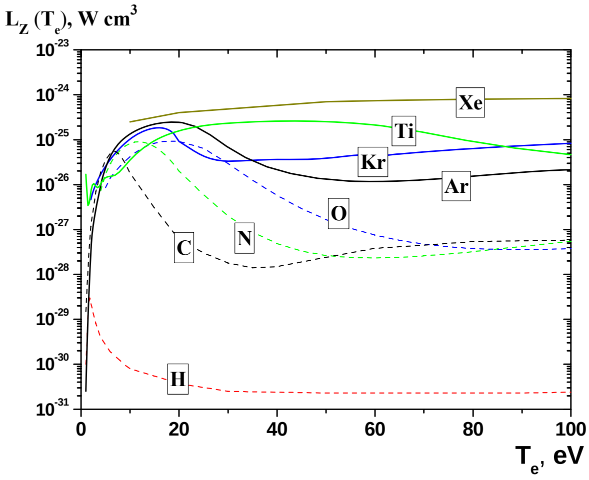

Fig.4. Radiation loss power for H [8], C [9], N [10], O [10], Ar [11], Ti [11], Kr [12], Xe [10]

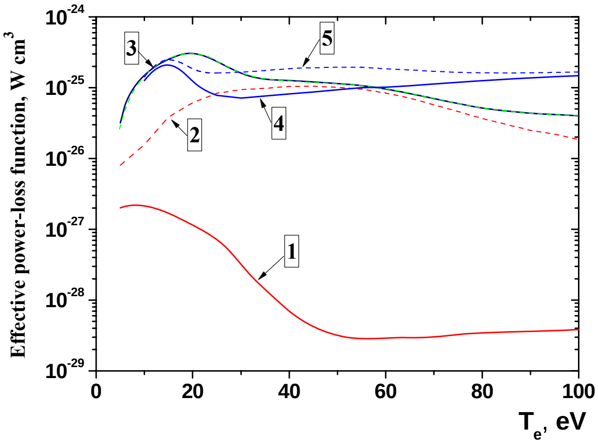

Fig.5. Effective radiation power loss for different impurities: 1 – H+0,05 C+0,01 N+0,01 O; 2 – H+0,4 Ti+0,05 C+0,01 N+0,01 O; 3 – Ar+0,4 Ti+0,05 C+0,01 N+0,01 O+0,03 H; 4 – Kr+0.079 Xe+0,45 N+1,1 10^{-3} O; 5 – Kr+0,4 Ti+0.079 Xe+0,55 N+0,05 C+0,01 O+0,03 H

CONCLUSIONS

Maximum values of the plasma radiation flux measured by means of a photodiode FDUK-13Y are 3.7×10^{-4} W (H_2+Ti), 4.5×10^{-4} W (Kr-Xe-N_2-O_2+Ti) for composite cathodes, the ratio of the radiation flux with the equal average density for Kr-Xe-N_2-O_2+Ti and H_2+Ti varies from 1.1 to 1.3. The main contribution in the total radiation flux is observed on the visible part of the spectrum (~to 80%). By the spectrometric method the basic components of gas-metal plasmas are determined and the quantity of impurities in the plasma formed was evaluated. The calculation results and experimental data are in a good accord.

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ИЗЛУЧЕНИЕ ГАЗОМЕТАЛЛИЧЕСКОЙ МНОГОКОМПОНЕНТНОЙ ПЛАЗМЫ ИМПУЛЬСНОГО ОТРАЖАТЕЛЬНОГО РАЗРЯДА

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Проведены измерения потока излучения газометаллической плазмы, образованой в среде поджигающего газа (газовой смеси) и распыленного материала катода, в импульсном отражательном разряде. Спектрометрическим методом определен состав образуемой газометаллической плазмы.

ВИПРОМІНЮВАННЯ ГАЗОМЕТАЛЕВОЇ БАГАТОКОМПОНЕНТНОЇ ПЛАЗМИ ІМПУЛЬСНОГО ВІДБИВНОГО РОЗРЯДУ

Ю.В. Ковтун, А.І. Скібенко, Є.І. Скібенко, Ю.В. Ларін, А.М. Шаповал, В.Б. Юферов

Проведено вимірювання потоку випромінювання газометалевої плазми, утвореної в середовищі запалювального газу (газової суміші) і розпорошеного матеріалу катода, в імпульсному відбивному розряді. Спектрометричним методом визначено склад утворюваної газометалевої плазми.