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P h y s i c s

MEASUREMENT OF DISCHARGES TEMPERATURE IN LOW-TEMPERATURE ACOUSTOPLASMA

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The results of temperature measurements in the Argon discharge in plasma with acoustic perturbation are presented. Possibility of, as decreasing, so increasing of discharge temperature in several times is shown.

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***Keywords*:** discharge temperature, low-temperature acoustoplasma.

Introduction. At interaction of acoustic waves with low-temperature plasma, a new acoustoplasma medium with parameters different from the usual low-temperature discharge plasma of direct current can be created [1–3]. One of the methods to create an acoustoplasma is as follows: in a discharge current, which contains a constant (direct) and a sinusoidal alternate components, acoustic oscillations are generated. These acoustic oscillations interact with the plasma and, under certain conditions [2–4], an acoustoplasma is created. The gas discharge temperature is an important factor in the evaluation of many plasma parameters. In a low-temperature direct current discharge plasma, the probe measurements of the temperature are usually used. This is either a thermocouple probe, or Langmuir probes [5]. However, any probe inserted into the discharge changes the discharge parameters. This is especially evident in a medium with acoustoplasma interaction, when a large alternate component of the discharge current appears. Our measurements in plasma with modulation of the discharge current showed, that if the value of the alternate component of the discharge current exceeds 50% of the value of direct current component, then with an average discharge current of 20 mA, the temperature measurement error of the standard thermocouple is $20-50\%$. This is due to the fact that the thermocouple, by its nature, is a rectifying contact that detects electric pickups from the discharge and when modulating the current gives a constant component that distorts the measurement result. It is most expedient to use remote methods of temperature measurements without introducing any additional bodies into the discharge. The use of classical

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pyrometers is difficult, because the plasma emission spectrum is different from the spectrum of the absolutely black body (ABB), for which the pyrometer is graduated. The most expedient is the measurement of temperature by radiometers-instruments that measure the spectral density of radiation. The dependence of the spectral density of the equilibrium radiation of the ABB on the temperature and wavelength is determined by the Planck law for thermal radiation. In the radio range, for $kT \gg h\nu$, instead of the Planck formula, use the approximate Rayleigh–Jeans formula:

$$\rho(\nu,\ T) = 2\pi\nu^2 c^{-2} kT, \tag{1}$$

where ρ is the spectral radiation density, ν is the radiation frequency, c is the speed of light, k is the Boltzmann constant and T is the temperature.

If the frequency response of the antenna-feeder path is uniform within the receiver's bandwidth, then the power of the radio-thermal signal at the output of the antenna-feeder device:

$$P_c = kT_m \Delta\nu, \tag{2}$$

where P_c is the power of the radio thermal signal, T_m is the measured temperature, $\Delta\nu$ is frequency band pass of the receiving path. The resulting total radiation of real objects is due to the object's own radiation and the reflection by this object of energy falling from the external environment [6]. It can be equated to the energy of an ABB with a temperature T_m:

$$T_m = T_{eq\ s} + T_{eq\ env}\chi = \varepsilon^{1/4} T_{true\ s} + T_{eq\ env}\chi, \tag{3}$$

where $T_{eq\ s}$ is the temperature of the ABB, which is equivalent in power to the signal from the real source, $T_{eq\ env}$ is the equivalent radiation temperature of the medium, χ is the reflectivity of the radiation source, ε is the equivalent emitting power of the source, $T_{true\ s}$ is the true source temperature. Thus, the measured temperature T_m is usually called apparent and is not true.

Experimental Setup. Under laboratory conditions, using a quartz discharge tube, we have obtained that $T_{eq\ env}\chi = 12.4\ K$ and this value can be neglected, i.e.

$$T_m \approx \varepsilon^{1/4} T_{true\ s}. \tag{4}$$

The developed microwave radiometer operated at a wavelength of $\lambda = 8$ *mm*. The experimental setup is shown in Fig. 1 and is described in detail in [7].

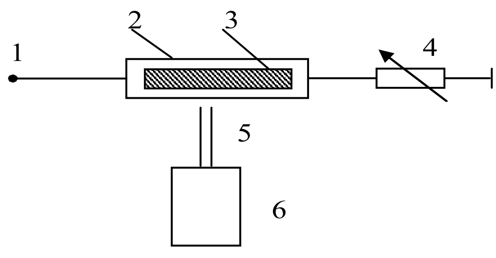

Fig. 1. Scheme of the experiment on the measurement of temperature by a radiometer:

1 – high-voltage constant voltage source;
2 – quartz discharge tube;
3 – plasma;
4 – electronically adjustable ballast;
5 – waveguide;
6 – radiometer.

In a cylindrical quartz discharge tube with an internal diameter of 25 *mm* and a discharge gap of 500 *mm*, a discharge was created, the apparent diameter of which varied from 20 to 1.5 *mm*. The discharge diameter depended on the gas pressure in the tube, the magnitude of the direct component of the discharge current, and the state of the acoustoplasma. The state of the acoustoplasma depended on the modulation frequency and the value of the alternate component of the discharge current, on the type of gas or gas mixture, and on the parameters of the acoustic resonator that is formed by the discharge tube.

A constant positive high voltage was supplied from the source (1) to the anode of the discharge tube (2) (Fig. 1). The cathode of the discharge tube was connected to an variable ballast impedance (4). The value of the ballast resistance was controlled in such a way that the discharge current had a direct and sinusoidal component. In the immediate vicinity of the plasma, a waveguide (5) was placed, the size of which was $4 \times 8\ mm^2$ (the narrow side of the waveguide is directed along the axis of the discharge). The waveguide was connected to a radiometer (6). Thus, not the temperature at the discharge axis or in the wall layer was measured, but the integral temperature over the discharge cross section, which is averaged over a $4-5$ *mm* segment along the discharge axis. The main contribution to this integral temperature is given by the temperature at the discharge axis. Experiments in an argon discharge are described below. The gas pressure in the tube varied from 12 to 400 *torr*, the amplitude of the sinusoidal component (I_{AC}) of the discharge current varied from 0 to 20 *mA*, the value of the direct component (I_0) was $20-30$ *mA*, the modulation frequency varied from 0.2 to 5.4 *kHz*. Below the frequency of 0.4 *kHz* there were no acoustic resonances, and above 5.6 *kHz* there were non-axial modes.

Results and Discussion. Two modulation modes were studied. In the first mode when the average value of the ballast resistance R_b is comparable with the negative differential resistance of the discharge R_d (but still $R_b > R_d$). In this mode with a low modulation frequency (below 40 *Hz*), the discharge blows out. At a frequency above 100 *Hz*, the discharge does not blow out, but the discharge current "hardly" followed the modulation of the ballast resistance (repeating the phase and shape). This mode was used for experiments, which are presented in Fig. 2. In Figs. 3–5 the "soft" mode $R_b \gg R_d$ are used. In this mode the discharge does not blow out even at a very low modulation frequency and very small values of the direct current component of the discharge. Figs. 2–5 show the results of measurements of the integral temperature T_m in an argon discharge using a microwave radiometer.

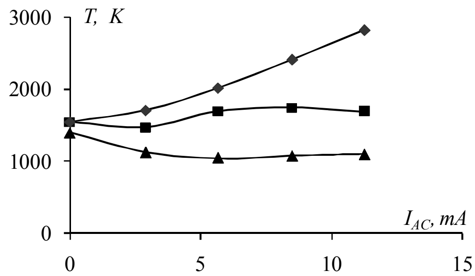

Fig. 2. Dependence of the discharge temperature T_m on the amplitude of the variable component of the discharge current I_{AC}. The modulation frequency is $f = 5.4$ *kHz*, the direct component of the discharge current is $I_0 = 30$ *mA*.

P_0= ◆ 400; ■ 200; ▲ 25.

Fig. 2 shows the dependence of the discharge temperature on the amplitude of the alternate component of the discharge current for three different values of the gas pressures in the tube. The direct current component of the discharge is $I_0 = 30$ *mA*, the modulation mode is "hard".

It can be seen from the Fig. 2, that at a pressure $P_0 = 25$ *torr*, with an increase of the modulation depth (the ratio of the alternate component of the discharge current to a direct component), the discharge temperature first decreases 1.5 times, and then remains constant. It was this mode that was used in a CO_2 laser to increase the generation power and increase the laser efficiency [8].

At a pressure of 200 *torr*, the discharge temperature is practically independent of the depth of modulation. At a pressure of 400 *torr*, the discharge temperature rises (2 times) with an increase in the modulation depth. This increase in temperature is due to the phenomenon of "acoustic contraction", i.e. a decrease in the discharge diameter with an increase in the depth of modulation [7,9,10]. It should be noted that in acoustic contraction with an increase in the alternate component of the discharge current, the diameter of the discharge decreases, and as the direct current component of the increases, the discharge diameter increases [9, 10]. Under normal thermal contraction in a plasma without acoustic perturbation, the discharge diameter decreases with increasing current [11].

In Fig. 3 the modulation mode is "soft". It follows from Figure, that at first the discharge temperature increases sharply with increasing pressure. After a pressure of 50 *torr*, the temperature increase slows down. In the absence of an alternate component ($I_{AC} = 0$), a "hump" is observed on the temperature curve for a pressure of 50 *torr*. One can see also that for $I_{AC} = 5.6$ *mA* the course of the curve after 100 *torr* almost does not differ from the case $I_{AC} = 0$. At $I_{AC} = 16.8$ *mA* in the pressure region above 100 *torr*, the temperature exceeds approximately 400 *K* the discharge temperature at a direct current, which is associated with acoustic contraction.

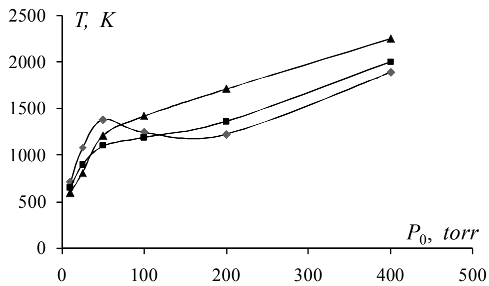

Fig. 3. Dependence of T_m on the gas pressure P_0 in the discharge tube. $f = 2$ *kHz*, $I_0 = 20$ *mA*.

I_{AC}= ■ 0; ▲ 16.8 *mA*; ◆ 5.6 *mA*.

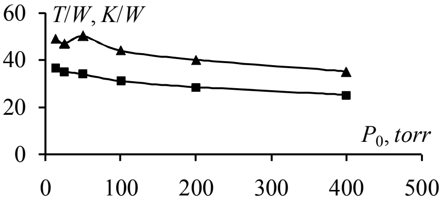

Fig. 4. Dependence of the normalized per unit power temperature T_m / W on the pressure in the discharge tube P_0; $f = 2$ *kHz*, $I_0 = 20$ *mA*.

■ 5.6 *mA*; ▲ 16.8 *mA*.

In Fig. 4 for the same values of the parameters as in Fig. 3 the temperature dependence normalized per unit of power T_m/W is given, here W is the electric power that is introduced into the discharge. The ratio T_m/W does not have a strict physical meaning, but it is a convenient parameter for estimating the energy deposition in the discharge and for describing the temperature change of the acoustoplasma when the discharge parameters change. This is important, since the electrical conductivity and the electric field strength in the discharge for acoustoplasma and plasma without acoustic disturbance differ [11].

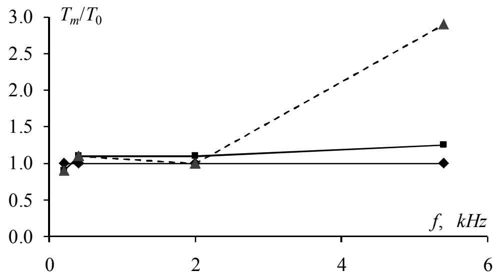

Fig. 5. Dependence of the normalized temperature T_m/T_0 on the modulation frequency. $T_0 = 1800\ K$, $P_0 = 400\ torr$, $I_0 = 20\ mA$.

I_{AC}= ◆ 0; --■-- 5.6 mA; ▲ 8.4 mA.

Fig. 5 shows the temperature dependence of the modulation frequency of the discharge current for three values of the discharge current alternate component. The ordinate shows the temperature values normalized to the temperature in the discharge of the direct current T_0. It follows from the Figure, that at a frequency of 5.4 kHz, with a sufficient depth of modulation (threshold effect), the discharge temperature increases (3 times), because of the phenomenon of "acoustic contraction" [7].

Conclusion. Achieved results allow to do the following conclusion:

- if in acoustoplasma to fix one of three parameters (pressure of gas in the tube, frequency and depth of modulation), by a selection two other, at the same value of the electric power entered in a discharge, it is possible in several times to change the temperature of discharges;

- this effect can find application in a laser technique, plasma-chemistry, gas-unloading sources of light and other regions of physics and technique.

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