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RADIATION TEMPERATURE MEASUREMENT OF ARGON ARC PLASMA BY SUBMILLIMETER DIAGNOSTIC TECHNIQUES

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Abstract: Methods of radiation temperature measurement of the plasma filament by active and passive submillimeter diagnostic are described. The profiles of the side-on brightness of plasma thermal emission are measured at two wavelengths, one of them being self-absorbed. These data are used to determine the radiation temperature and optical depth of plasma [1]. Simultaneous probing of the plasma filament by submillimeter radiation at two wavelengths allows to check this method and find out the degree of plasma equilibrium as well as the nature of electron collisions.

Experiment: Diagnostic installation consists of D.C. arc, heterodyne H_2O-laser (\( \lambda =119\,\mu m \)) [2] interferometer, homodyne backwave tube (BWT, \( \lambda =350\,\mu m \)) interferometer, high sensitive two-channel radio-meter and measuring apparatus.

Fig. 1 shows the cross-section of D.C. arc chamber (1) (10x10x10 cm^3). Its diagnostic windows (2) were made of crystalline quartz. The arc electrodes (50 mm apart) were cooled by water and have molybden tips (4). To facilitate the local side-on diagnostic of plasma by narrow submillimeter beams formed by the lenses (7), the plasma filament is moved with a frequency about several Hz by oscillating magnetic field H of the coils (6).

Fig. 2 Diagnostic set-up: P_1-P_6 - one-dimensional grids (period 20\,\mu m), M_1-M_4 - metal mirrors, L_2-L_4 - polyethylene lenses (diameter-54 mm, focal length-140 mm).

Optical system of the experimental installation (Fig. 2) is a twin-wave Mach-Zehnder interferometer. H_2O-laser radiation consists of two orthogonally polarized waves with a frequency shift 18 kHz, orientated at the angles of \(-45^\circ\) and \(+45^\circ\) to the vertical. It is directed into the interferometer by means of mirror M_1. BWT-radiation is formed in the quasi-optical beam by the lens L_1. Horizontal polarization, provided by polarizer P_5, is directed into the interferometer by the mirrors M_1 and M_2 and grid G_1. The frequency of BWT radiation is modulated by saw-tooth law with a frequency of 27 kHz. At the output of the interferometer there are vertically orientated polarizer P_3 and two-channel detector D_1 with photodetectors n-GaAs and Ge:B at 4.2 K. The transmittivity signal G(\( \rho \)) (\( \lambda =350\,\mu m \)) is detected by n-GaAs at 27 kHz. Laser signal (\( \lambda =119\,\mu m \)) is detected by Ge:B at 18 kHz and employed to measure phase.

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shift \( \mathcal{V}(\varphi) \) by fast "phase-voltage" converter [3]. \( D_2 \) signal is used as the reference one. The distribution of plasma emission is measured by two-channel radiometer \( D_2 \) at 108 \( \mu \)m (GeB) and 285 \( \mu \)m (n-GaAs).

Functions \( \mathcal{V}(\varphi) \), \( s(\varphi) \) and spectral brightnesses \( I_{285}(\varphi) \) and \( I_{285}(\varphi) \) are registered by the two-beam oscilloscopes OSC\(_1\) and OSC\(_2\).

The impact parameter \( \varphi \) is measured by the scanner system [4].

**Results:** Typical experimental curves are shown in Fig.3a-b. Data processing is performed under assumption that plasma temperature gradients are negligible, In this case one obtains from radiation transfer equation the expression for \( J(\varphi,\lambda) \):

\[ I(\mathcal{V}_0) = B(\mathcal{V}_0) \left( \exp (-\mathcal{T}) - 1 \right) \left( \exp (-\mathcal{T}) - 1 \right) \]

(1)

where \( B(\mathcal{V}_0) \) is blackbody spectrum, \( \mathcal{T}(\mathcal{V}_0) \) is plasma optical depth at \( \varphi = 0 \), \( \mathcal{T}_e \) is the mean radiation electron temperature and \( \mathcal{V} \) is wave number. If \( I_1 \) and \( I_2 \) are the surface brightnesses at two frequencies \( \mathcal{V}_1 \) and \( \mathcal{V}_2 \), then using eqn.(1) one can calculate the plasma optical depth at the frequency \( \mathcal{V}_2 \) \( (\mathcal{V}_2 < \mathcal{V}_1) \) from eqn.:

\[ I_1/I_2 = \mathcal{Y} \left( \frac{1}{1 - \exp (-\mathcal{T})} \right) \left( \frac{1}{1 - \exp (-\mathcal{T})} \right) \]

(2)

where \( \mathcal{Y} = \left( \frac{\sqrt{2}}{1 + \sqrt{2}} \right) \) \( (\gamma = 0.144 \) for n-GaAs and Ge:B detectors). Radiation temperature (in K) is given by the formula:

\[ \mathcal{T}_e^2 = 3.9 \cdot 10^2 \frac{I_2}{I_1} \left( 1 - \exp (-\mathcal{T}) \right) \]

(3)

where \( I_2 \) is brightness in \( \mu \text{W/cm}^2 \cdot \text{cm}^{-1} \). \( \mathcal{T} \) is the root of eqn.(2). Plasma optical depth \( \mathcal{T} \) is measured independently using modulus of the complex transmittivity \( s(\varphi) \) at the frequency \( \mathcal{V} = 28.6 \text{ cm}^{-1} \) \( (\lambda = 350 \mu \text{m}) \) : \( s(\mathcal{V}) = \exp [-\mathcal{T}(\mathcal{V})/2] \).

Fig.3c shows the optical depth of the Ar discharge for regimes of constant current 18.2 A.

In the pressure range of 1-2.25 atm the mean radiation temperature \( \mathcal{T}_e^2 \) within experimental errors is independent on the gas pressure \( P \) and is equal to \( (7.3 \pm 1.5) \cdot 10^3 \) K. On the other hand, phase measurements show that electron density is proportional to \( P^{1/2} \), as it must be at the equilibrium. In this case linearity of the function \( \mathcal{T}(\varphi) \) gives an evidence that electron-ion collisions dominate other collision processes. The equilibrium temperature \( \mathcal{T}_e^2 \) at \( \varphi = 0 \) calculated by Saha equation, is equal to \( 9.2 \cdot 10^3 \) K, i.e. it is 10-20% higher than \( \mathcal{T}_e^2 \).