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Probe diagnostics of a small microwave discharge at atmospheric pressure

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Electron temperature and electron density in atmospheric microwave plasma source are obtained by double probe. The electron energy distribution function obtained by solving the Boltzmann equation is close to Maxwellian at our experimental conditions allowing the application of double probe diagnostics.

Technological applications of atmospheric pressure plasma in the industrial processes require a simple and effective technique for monitoring of the plasma parameters. Double probe diagnostics is generally preferred in the electrodeless discharges. Electron temperature and plasma density can be calculated from the current-voltage probe characteristic with an appropriate theory applied for the electron and ion currents collected by the probe electrodes in atmospheric pressure plasma. The standard formula for the calculation of the electron temperature by double probe characteristic is applicable if the electron energy distribution function is Maxwellian. Initial information for gas-discharge parameters such as gas temperature, gas flow velocity, electron temperature and density is necessary to select proper probe regime and to apply reliable theory for the ion saturation current.

This study presents a double probe diagnostics system for determination of the plasma parameters of a small portable microwave plasma source based on a surface waves sustained discharge at 2.45 GHz [1]. This source works with argon gas at atmospheric pressure both in continuous and pulse regimes.

A self-consistent model of the discharge is used for the determination of the electron energy distribution function for different values of the absorbed microwave power. The model includes the dispersion relation of the azimuthally-symmetric surface waves creating a plasma column in a ceramic tube with an inner diameter of 1 mm and length of 11 mm. The EEDF is obtained by solving the Boltzmann equation under the local approximation condition. A collisional-radiative model is applied for the determination of the level populations of exited argon atoms, atomic Ar^{+} ions, molecular Ar^{2+} ions and exited molecules $Ar2^{*}$ in the plasma column. The results show that EEDF is close to Maxellian for electron densities above 2.10^{20} m^{-3} while at lower densities a significant deviation exists. The plasma parameters of the discharge are estimated from double probe characteristics in both continuous and pulse regimes. The probe has two cylindrical electrodes: tungsten wire with diameter of 0.2 mm and length of $l \leq 1$ mm positioned in the middle of the plasma column through a small hole and second one with diameter of d = 0.3 mm and length of 3 mm (Fig. 1) at the top of the ceramic tube.

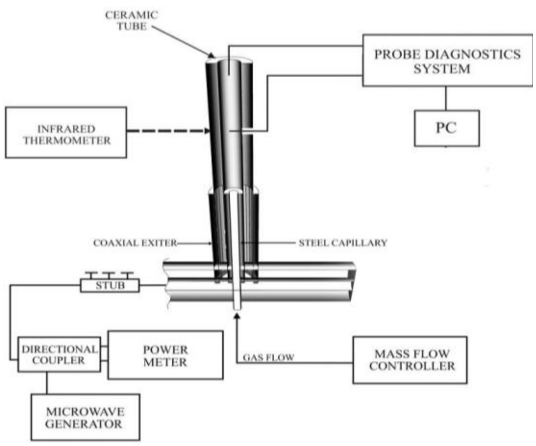

Fig. 1: Experimental setup with double probe.

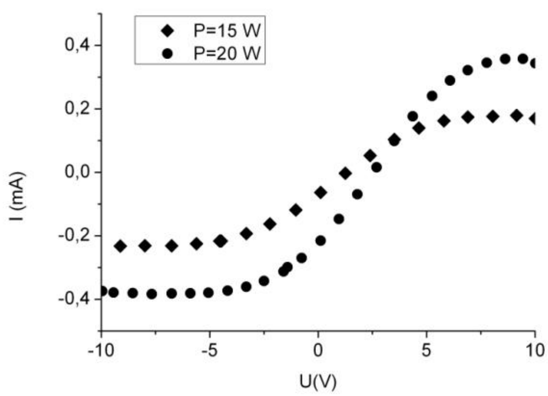

Fig. 2: Double probe characteristics.

The volume of the first electrode is less than 0.36 % from the plasma column volume. Its maximum cross-section perpendicular to the gas flow can reach 25% from the cross-section of the tube and this electrode affects the flow rate. The probe electrodes cause increase of the reflection of the microwave signal, especially at short plasma columns. Additional matching is applied and the forward and reflected power is measured by directional coupler. The surface waves sustain the discharge in the presence of probe electrodes in the ceramic tube.

The acquisition system is based on averaging of the current-voltage characteristics over many periods of the ramp voltage or on the fixed number probe characteristics in a single pulse. The obtained characteristic is smoothed and its slope is calculated by differentiation procedure. The electron temperature is calculated by the standard formula (T_e = 1.7±0.2 eV) and it is compared with the result from the model. The value of the plasma density is obtained from the ion saturation current of the cylindrical probe positioned in the middle of the discharge tube using the modified theory [2] for a probe in high pressure flowing plasmas. The results obtained for the averaged value of the plasma density over the radius show a nonlinear dependence on the applied microwave power. The obtained probe characteristics at 15 W and 20 W of the applied microwave power at gas flow rate F=300 sccm are presented in Figure 2. The results for the plasma density (n_e = 4.10^{20} - 8.10^{20} m^{-3}) show a nonlinear dependence on the applied microwave power.

References

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