Publ. Astron. Obs. Belgrade No. 84 (2008), 301 - 304 *Contributed Paper*

DETERMINATION OF PLASMA ELECTRON DENSITY BY MICROWAVE RESONANCE PROBE

D. POPOVIĆ, J. VUČETIĆ and V. MILOSAVLJEVIĆ†
Faculty of Physics, University of Belgrade, P.O.B. 368, Belgrade, Serbia
E–mail: †*vladimir@ff.bg.ac.rs*

Abstract. The time-dependent spatial electron density distribution in a constricted, pulsed plasma source is measured using a floating microwave hairpin resonance probe and an extrapolation method is used for determining the peak in electron density from the experimental data. Using these techniques a detailed characterization of the spatio–temporal evolution of the electron density, outside the constricted region above the anode of the pulsed plasma source is presented.

1. INTRODUCTION

It is desirable to develop/demonstrate a remote plasma diagnostic to prevent possible affects on constricted plasma column/channel which could be caused by placing a probe there and to remove interference with the application of other diagnostics like laser interferometric measurement, absorption spectroscopy or self–absorption measurement (doubling optical path by putting reflecting mirror). To realize the remote diagnostic, a hairpin probe is introduced to the discharge tube volume (extended pocket) outside of the constricted channel and opposite to the electrode. The electron density is found to fall sharply with the distance from the constructed channel. By modeling the electron density in time and space we develop the method to calculate electron density in the constricted channel from our remote diagnostics.

In the paper Milosavljević et al. (2007), the hairpin technique is used only along the axis of the constricted channel and in conjunction with OES. Interpretation of the results was based on the knowledge of the peak density. In this paper, we further consolidate the curve–fitting technique to interpret approximate values of the peak density evolution in the direction perpendicular to the constricted channel of the discharge tube without using OES measurement. Our main motivation in the present work is to (1) measure the electron density along the direction perpendicular to the constricted channel, (2) validate the robustness of the extrapolation technique, (3) verify the electron density projected by measurements perpendicular to the constricted channel to measurement made along the constricted channel, (4) to establish using hairpin as a remote probe to determine the time–window when the OES technique are useful for the study of plasma density along the constricted channel of discharge tube.

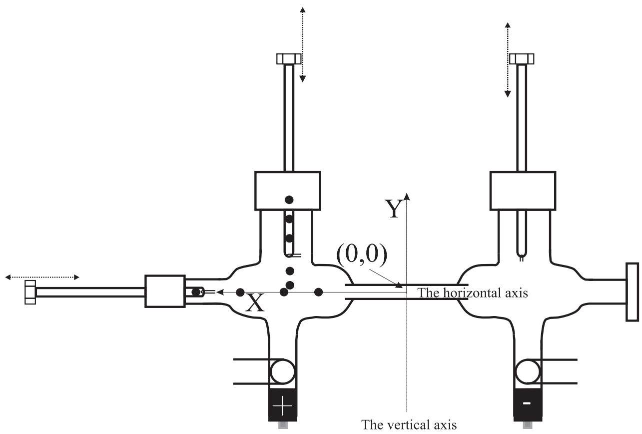

Figure 1: Diagram of the plasma source. The positions where the electron density has been measured are denoted with black circles on the Anode-side extended pocket.

2. EXPERIMENTAL SETUP & DIAGNOSTICS TECHNIQUES

The modified version of the linear, low pressure, pulsed arc (Djeniže et al. 1992,1998; Milosavljević et al. 2003) is used as the plasma source. A pulsed discharge was driven in a pyrex tube of 5 mm inner diameter and effective plasma length of 72 mm Figure 1. The tube has an end–on quartz window. The working gas is helium–argon mixture (He(28%)+Ar(72%)) at 130 Pa filling pressure in flowing regime. A main capacitor of 14 μF is charged to 1.8 kV, yielding 15.8 J dissipation energy. To facilitate introduction of the probes into the plasma source, we have change our original glass tube (see Fig. 1 in Djeniže et al. 1998) providing three ports; Two on the top of the expanded glass tube sections, and one on the side aligned with the constricted channel. The second quartz window remains for the observation of spectral line shapes by spectrometers. The main dimensions of the tube have not been changed. More details about experimental set–up is presented in Milosavljević et al. (2007).

The principle of the microwave hairpin resonance probe is based on measuring the plasma dielectric constant, ε_p, using a microwave resonant structure Karkari & Ellingboe (2006). The hairpin consists of a 1/4 wavelength parallel transmission line with one end short–circuited and the other end open, with the plasma as the dielectric medium of the transmission line. When the resonator is immersed in plasma it's self–resonant frequency shifts from the characteristic resonance frequency in vacuum.

The electron density is directly obtained from the shift in the characteristic resonance frequency according to the formulae Karkari & Ellingboe (2006), Milosavljević et al. (2007).

$$N_e/10^{10}cm^{-3} = \frac{(f_r/GHz)^2 - (f_o/GHz)^2}{0.81}. \quad (1)$$

Where f_r and f_o are the resonance frequencies in plasma and in vacuum. For all hairpin measurement the alignment of the probe tip itself is parallel to the constricted channel.

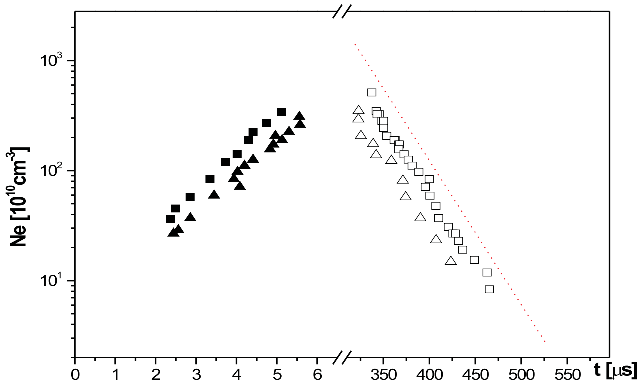

Figure 2: Measurement of the electron density at two position close to each other, from the top port: x=48mm, y=4 mm (square) and from the side port: x=50mm, y=0mm (△). Full and empty symbols represents creation and decay phase, respectively. The dotted line represent extrapolated curve for position x=48 mm and y=0 mm.

3. RESULTS AND DISCUSSION

Electron density is measured during the creation and decay of the plasma by floating hairpin probe. We have performed hairpin measurements in vertical axis at y=4, 10, 35, 43 and 50 mm from the constricted channel, and for all 5 y–position the x is 48mm, 13mm from the end of the narrow part of the tube. Previous measurements along the horizontal axis at x=45, 50, 58, and 67 mm, has been presented in Milosavljević et al. (2007).

In the Figure 2 are presented electron densities measured around coordinate (48,0) (this point is in the constricted channel). This coordinates is relevant because of two hairpin measurement which have been done very close to each other, i.e. along horizontal and vertical axis. These two hairpin measurement are done at the position (48,4) and (50,0) for the probe introduced from the top and from the side port, respectively. The hairpin position from the top port (48,4) is the closest one from all 5 measured, to the constricted channel. The features show a characteristic rise in electron density in the creation phase and comparatively slower decay in density in the decay phase measured by the both probe, i.e. for the axial and perpendicular probe. The data in the Figure 2 shows very similar trends and that is expected, since the probe tip from the side port is a straight and from the top port is perpendicular to the probe itself, i.e. both probe tips have same orientation in respect to the constricted channel. Thus, verification of the hairpin data taken along two direction, perpendicular to each other, is done by comparing the result of electron density direct measured along axial port with electron density gotten by extrapolation technique, from the top port hairpin measurement.

The extrapolated curves for experimental data collected at (48,4) and (50,0), as well extrapolated curve at (48,0) presented in Figure 2 pass very close to independed determinate electron density by OES Milosavljević et al. (2007). This also gives a possibility of using hairpin probe for estimate of electron density at a constricted channel, even in case the measuring of electron density in the constricted channel is not possible due to construction limitation of plasma chamber, like other diagnostics already applied (Interferometry, OES, ...) or a lack of port at the chamber. So, hairpin probe can be use as remote sensor for electron density measurement.

Extrapolation technique used in this work is different one from previously used in Milosavljević et al. (2007), because we introduce a possibility that free parameters in previous work constants are changed along y–axis.

4. CONCLUSION

We have applied a floating microwave hairpin resonance probe, yielding the spatially–temporal resolved electron density during both the breakdown phase and the decay phase of the plasma. The hairpin probe data is collected for vertical position, i.e. perpendicular position to the constricted channel.

The extrapolation technique, was used to obtain an approximate value of the peak electron density for the axial probe measurement, is changed to be more robustness one by introducing a fitting over y–coordinate and excluding the constraint that the peak density must matches with the peak in discharge current recorded by Rogowskii coil.

In the paper we present also the possibility of extracting the information related to electron density in the constricted channel, even when the measurement of electron density in the constricted channel is not possible due to construction limitation of plasma chamber by using so–called remote hairpin probe. This become possible after we change the extrapolation technique. This is done by setting the value for y position to zero. The same analyze help us to validate data around coordinate (48,0) in constricted channel. The results shows consistent agreement of the measured density using the axial and the perpendicular probe at (48,0).

Comparison the data taken at almost same point in the discharge tube, from the side port (x=50mm; y=0mm) and from the top port (x=48mm; y=4mm) we demonstrated the position of probe tip in respect to the probe itself is not so critical. Therefore the results shows consistent agreement of the measured density using the axial and the perpendicular probe around the (48,0) point.

Acknowledgments

This work is a part of the project "Nonlinear dynamical phenomena in photorefractive media, liquid crystals, plasmas and left–handed materials (OI141031)" supported by the Ministry of Science and Environment Protection of the Republic of Serbia. Authors are grateful to Dr. S. Karkari for help.

References

Djeniže, S., Milosavljević, V., Srećković, A.: 1998, *J. Quant. Spect. Rad. Transfer*, **59**, 71.
Djeniže, S., Srećković, A., Labat, J.: 1992, *Astron. Astrophys.*, **253**, 632.
Karkari, S., Ellingboe, A. R.: 2006, *Appl. Phys. Lett.*, **88**, 101501.
Milosavljević, V., Djeniže, S., Dimitrijević, M. S.: 2003, *Phys. Rev. E*, **68**, 016402.
Milosavljević, V., Karkari, S., Ellingboe, A. R.: 2007, *Plas. Sour. Sci. Technol.*, **16**, 304.