Impedance probe and dc probe studies on a collisional plasma in an arc discharge

J. Basu and C. Sen

Citation: Journal of Applied Physics **46**, 2298 (1975); doi: 10.1063/1.321826
View online: http://dx.doi.org/10.1063/1.321826
View Table of Contents: http://scitation.aip.org/content/aip/journal/jap/46/5?ver=pdfcov
Published by the AIP Publishing

Impedance probe and dc probe studies on a collisional plasma in an arc discharge

J. Basu and C. Sen

Saha Institute of Nuclear Physics, Calcutta-9, India
(Received 24 May 1974; in final form 25 October 1974)

The collision-dominated plasma of a hot-cathode arc discharge in argon has been studied by a plane probe acting simultaneously as a rf impedance probe and a dc probe. Measurements carried out under different discharge conditions show that the electron temperatures, as given by the rf and dc methods, are in excellent agreement and that the corresponding electron densities agree fairly well, the agreement being better than that mentioned earlier for the plasma of a glow discharge. The thickness of the probe sheath as a function of the sheath voltage, as measured by the rf method, is reported.
PACS numbers: 52.70., 52.70., 52.80.M.

The rf impedance probe[1–4] and the Langmuir dc probe[5,6] are often used for measuring plasma parameters. However, these are, in general, confined to the study of collisionless plasmas. The characteristic of a dc probe embedded in a collisional plasma has attracted considerable attention,[7] but the work in this field is mostly theoretical in nature. The collisional plasma of a glow discharge in air has recently been investigated by the present authors[8] by using a plane probe simultaneously as an impedance probe and a dc probe and by modifying suitably both the probe methods so as to take into account the effect of the presheath lying between the probe sheath and the undisturbed plasma. It was noted that the electron temperatures, as given by the rf and dc methods, were in good agreement while the corresponding electron densities differed by a factor of 2–3. As the results were derived on the basis of an empirical model of the presheath, it seemed worthwhile to test the modified methods on a collisional plasma belonging to a different type of discharge. Moreover, the plasma has been so selected as to make the sources of error existing in the previous experiment less effective. The electron temperature and electron density, as measured in this case, are reported in this communication which also presents the thickness of the probe sheath for various values of the sheath voltage and under different discharge conditions.

The plasma used was the positive column of a hot-cathode arc discharge in argon; the gas was fed, through a needle valve, into the discharge tube which was continuously pumped. The discharge tube was 10 cm in diameter and 75 cm in length, while the probe was a nickel disk 6 mm in diameter, placed at a distance of 8 cm from the anode plane. The experimental arrangement and the probe system, shown in Fig. 1, were similar to those described by the authors elsewhere.[8] The frequency used for rf measurements was 1.5 MHz. The rf signal applied to the probe was kept small so that the small-signal approximation[9] could be used in the analysis.

Each set of experiments corresponded to fixed values of discharge parameters. The probe which was suitably cleaned to avoid contamination effects was kept at the plasma boundary and measurements were carried out for a number of bias voltages, the negative bias being reduced gradually from the floating potential. The probe impedance as well as its dc voltage and current were noted in each case. The stray effects in the impedance measurement could be eliminated by noting the impedance with the discharge off.

The electron temperature T_e, electron density in the unperturbed plasma n_0, and sheath thickness s for a negative probe have been determined from the experimental data in the same way as described earlier[8] for a glow discharge. The working equations are as follows:

$$R - jX = (R_t - jX_t) - (R_1 - jX_1), \tag{1}$$

$$\ln(1 + c^2) = (2R/X)(c - \tan^{-1} c), \tag{2}$$

$$s = 2bcR/\ln(1 + c^2), \tag{3}$$

$$R_s = cs/2b, \tag{4}$$

$$\ln R_s = \tfrac{1}{2}\ln(2\pi m_e kT_e) - \ln(An_{p0}e^2) - eV/kT_e, \tag{5}$$

$$I = An_{p0}e(kT_e/2\pi m_e)^{1/2}\exp(eV/\kappa T_e), \tag{6}$$

$$V = V_t - R_p(I - I_0), \tag{7}$$

$$n_0 = n_{p0}\exp(eR_pI_0/kT_e), \tag{8}$$

$$R_p = R_1 + X_1^2/R_1, \tag{9}$$

where $R - jX$ is the sheath impedance, $R_t - jX_t$ is the total probe impedance, $R_1 - jX_1$ is the presheath impedance (which can be obtained from the rf character-

TABLE I. Electron temperature and electron density at a constant pressure $P = 0.022$ Torr.

I_D (mA)	T_e (10^4 °K) by rf method	T_e (10^4 °K) by dc method	n_0 (10^9 cm^{-3}) by rf method	n_0 (10^9 cm^{-3}) by dc method
60	3.79	3.53	2.3	3.2
100	3.77	3.33	3.1	4.1
200	3.58	3.53	4.1	4.6

TABLE II. Electron temperature and electron density with a constant discharge current $I_D = 100$ mA.

P (Torr)	T_e (10^4 °K) by rf method	T_e (10^4 °K) by dc method	n_0 (10^9 cm^{-3}) by rf method	n_0 (10^9 cm^{-3}) by dc method
0.022	3.77	3.33	3.1	4.1
0.11	2.57	2.27	8.4	7.1

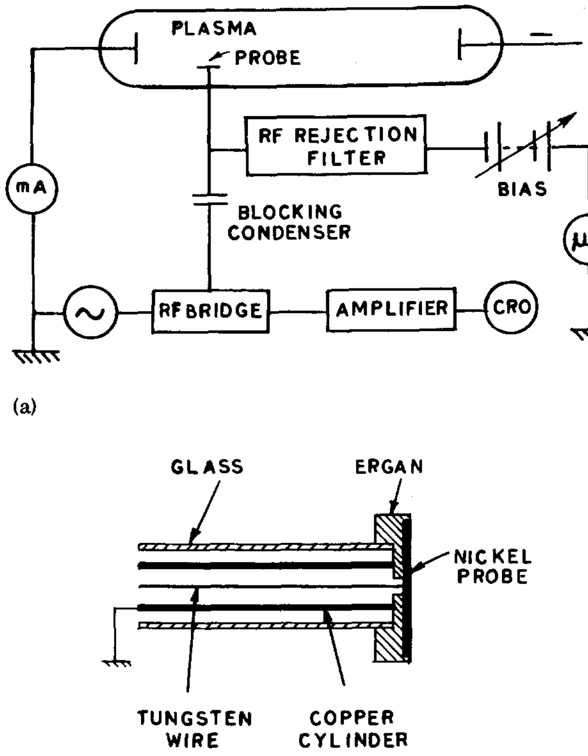

FIG. 1. (a) Experimental arrangement. (b) Probe system.

istics), $b=\omega\epsilon_0 A$, ω is the operating frequency, ϵ_0 is the absolute permittivity of free space, A is the probe area, R_s is the incremental dc resistance of the probe,

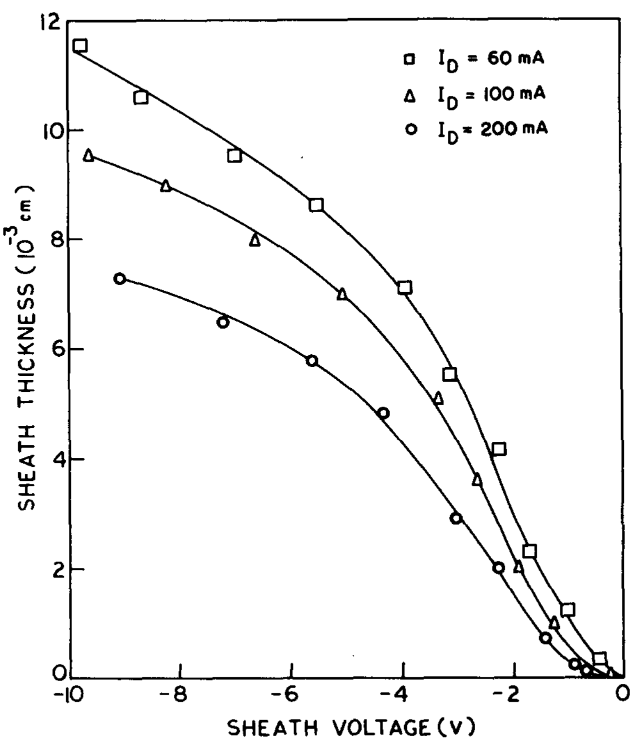

FIG. 2. Sheath thickness as a function of sheath voltage for three values of the discharge current I_D at a constant pressure $P=0.022$ Torr.

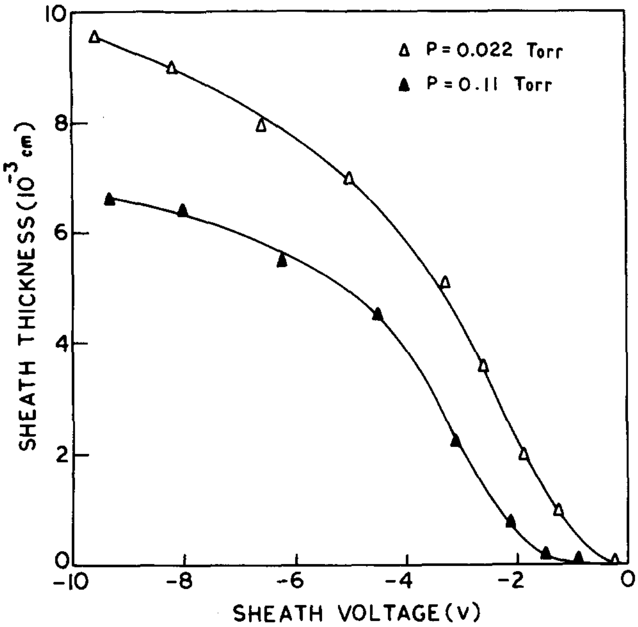

FIG. 3. Sheath thickness as a function of sheath voltage at two different pressures P with a constant discharge current $I_D=100$ mA.

k is the Boltzmann constant, m_e is the mass of an electron, $-e$ is the charge on an electron, n_{p0} is the electron density at the presheath edge with the probe at the space potential, V is the voltage across the sheath, V_t is the probe voltage with respect to the unperturbed plasma, I is the probe dc current, and I_0 is the same with the probe at the space potential. The electron temperatures and electron densities, as measured essentially by the rf and dc methods, are given in Tables I and II, while the sheath thickness is shown in Figs. 2 and 3.

The electron temperatures given by the two methods are found to be in excellent agreement. The electron densities also agree fairly well, differing by a factor of 1.1–1.4, as against a factor of 2–3 in the case of the glow discharge mentioned in Ref. 8. The better agreement can be ascribed to the following facts:

(a) The diameter and length of the glow discharge were 5 and 25 cm, respectively, while the probe used was a disk 1.1 cm in diameter. The ratio of probe dimensions to plasma dimensions was much smaller in the present case, the error due to the relatively large size of the probe[6,10] is considerably reduced.

(b) The absence of negative ions in the argon discharge removes a source of error existing in the air discharge.

The variation of the sheath thickness with sheath voltage, discharge current, or operating pressure is of the same nature as in the case of the glow discharge. The fact that the sheath is now, in general, thinner for the same sheath voltage is as expected in view of the appreciably greater magnitude of the electron density.

The authors are indebted to Professor D.N. Kundu, Director, Saha Institute of Nuclear Physics, Calcutta, for his valuable support.

[1]R.F. Mlodnosky and O.K. Garriot, in *Proceedings of the International Conference on Ionosphere* (Institute of Physics and the Physical Society, London, 1962), p. 484.
[2]F.W. Crawford and R. Grard, J. Appl. Phys. **37**, 180 (1966).
[3]B.M. Oliver, R.M. Clements, and P.R. Smy, J. Appl. Phys. **41**, 2117 (1970).
[4]P.J. Baum and J. Pollack, J. Appl. Phys. **44**, 163 (1973).
[5]I. Langmuir and H.M. Mott-Smith, Gen. Electr. Rev. **27**, 469 (1924); **27**, 538 (1924); **27**, 616 (1924); **27**, 762 (1924); **27**, 810 (1924).
[6]L.B. Loeb, *Basic Processes of Gaseous Electronics* (University of California Press, Berkeley and Los Angeles, 1961), Chap. 4.
[7]See, for example, R.L.F. Boyd, Proc. Phys. Soc. B **64**, 795 (1951); C.H. Su and S.H. Lam, Phys. Fluids **6**, 1479 (1963); J.F. Waymouth, Phys. Fluids **7**, 1843 (1964); I.M. Cohen, Phys. Fluids **13**, 889 (1970); Sin-Li Chen, Jen-Shih Chang, and S. Matsumura, J. Appl. Phys. **42**, 499 (1971); A.M. Whitman, Phys. Fluids **14**, 1115 (1971).
[8]C. Sen and J. Basu, J. Phys. D **6**, 172 (1973).
[9]J. Basu and C. Sen, Proc. IEEE **55**, 1767 (1967).
[10]J.D. Swift and M.J.R. Schwar, *Electrical Probes for Plasma Diagnostics* (Iliffe, London, 1970), Chap. 11.