Topic number: 5

LANGMUIR PROBE MEASUREMENTS OF ELECTRON DENSITY AND ELECTRON TEMPERATURE IN ARGON GLOW DISCHARGES - APPLICATIONS IN DISCHARGE MODELING

Ihor Korolov(1), Aranka Derzsi(1,2), Péter Hartmann(1), János Karácsony(1,2), Gergely Bánó(3), Zoltán Donkó(1∗)

(1) Research Institute for Solid State Physics and Optics of the Hungarian Academy of Sciences, H-1525 Budapest, POB 49, Hungary
(2) Babeş-Bolyai University, 400084 Cluj-Napoca, M. Kogâlniceanu 1, Romania
(3) Department of Biophysics, P. J. Šafarik Univ. Košice, 04001 Jesenna 5, Košice, Slovakia
(∗) **donko@mail.kfki.hu**

The validation of discharge models requires comparison of their results with reliable experimental data for a wide range of operating conditions. Phelps has compiled such a data base of electrical characteristics of low-pressure DC glow discharges in argon [1]. We are, on the other hand, not aware of any data compilation concerning other characteristics, e.g. measured electron density and electron temperature values for a wide range of discharge conditions. This lack of data is perhaps one of the reasons why the verification of the models present in the literature has been neglected in the majority of works. Here we present (i) systematic Langmuir probe measurements of the electron density as well as the elecron temperature in dc argon discharges and (ii) carry out calculations based on different fluid and hybrid models of the discharge [2]. In the models we use the measured electron temperature values and check the consistency of the measured and calculated charactersitics in term of voltage-current curves and electron density.

The discharge is generated between two parallel plate electrodes of 7.7 cm diameter separated by a distance of 3 cm. The probe is placed on the discharge axis in the middle of the anode-cathode distance. The probe characteristics are recorded for discharge current values in the range of I = 1 – 5 mA at pressures between p = 13 Pa and 107 Pa. An example of a measured Langmuir probe current-voltage characteristic is shown in Fig.1 in which the main steps of the evaluation procedure are also illustrated.

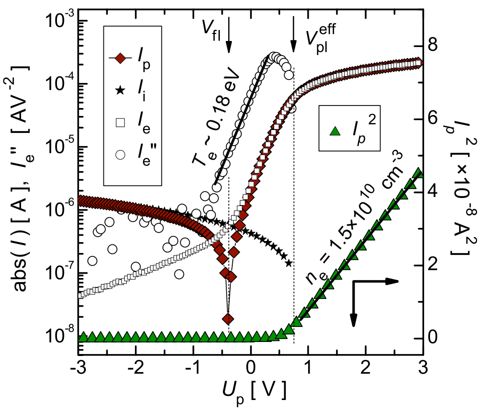

Fig. 1: An example of the measured Langmuir probe characteristic $|I|$ and its second derivative I'' (left scale), and I^2 (right scale) in the argon glow discharge at p = 40 Pa and I = 2 mA. V_{pl} and V_{fl} are the plasma and floating potentials, respectively [2].

First, the second derivative of the total probe current is calculated. The position of the effective plasma potential V_{pl}^{eff} is chosen to be at the zero crossing of the second derivative curve. A preliminary estimate of the electron temperature is obtained by fitting the second derivative with an exponential decay in the electron retardation region close to the plasma potential. Next, the ion part I_i of the probe current is estimated according to [3]. Once the ion current is obtained, the electron current I_e is calculated. The second derivative of I_e is calculated and fitted by an exponential function to obtain the temperature of the slow electrons. The electron density is determined from the slope of the square of the probe current I_p^2 as the function of the probe potential U_p in the electron accelerating region of the characteristic ($U_p > V_{pl}^{eff}$) [4].

Our measurements resulted in electron densities nearly proportional to the current at any fixed pressure. The density at the position of the probe exhibits a maximum as a function of pressure, which is a combined effect of the change of the magnitude of the density and the change of the spatial density profile, as a consequence of changing pressure. The electron temperature kT_e has been found to grow both with increasing pressure and with increasing current, acquiring values between 0.1 eV and 0.35 eV.

The modeling studies include a hybrid approach and a set of fluid models both neglecting and including the equation for mean electron energy (i.e. the 3rd moment of the Boltzmann equation). We call these fluid approaches, respectively, as "simple" and "extended" fluid models. We also compare the results obtained with different approaches used for the calculation of the ionization source: the flux-based and rate coefficient-based ways [2]. The models require the input of electron temperature, for this we use the experimentally determined values. The measured electrical characteristics and electron densities (at the probe location) serve as the basis of comparison. Fig.2 shows this comparison. Concerning both the electron density (Fig.2a) and current density (Fig.2b), the calculated results provided by the hybrid model are closest to the experimental values. The different fluid models show poorer agreement, especially in terms of electron densities.

This work has been supported by the Hungarian Scientific Research Fund (OTKA-K77653), and by the GLADNET FP6 MRTN-CT-035459 project.

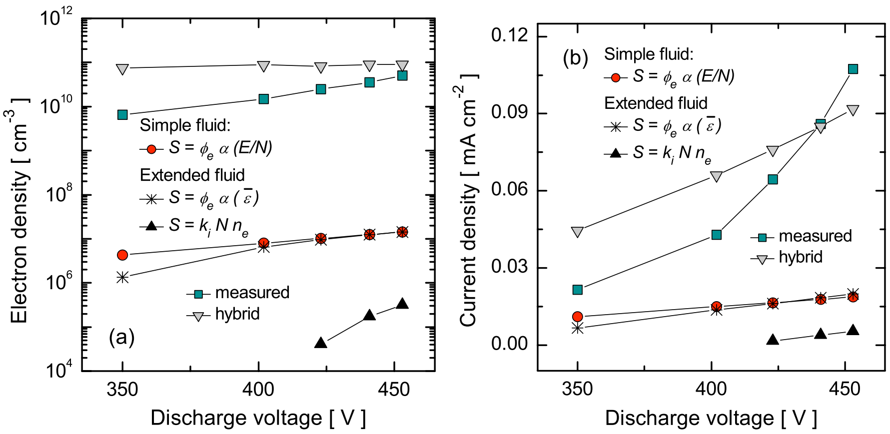

Fig. 2: Electron density at x=1.5 cm from the cathode (a) and current density (b), as a function of discharge voltage at $p = 40$ Pa. $\gamma = 0.033$ was used in all calculations [2].

Reference

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