Measurements of a DC Gas Discharge

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INTRODUCTION

DC gas discharges are partially ionized plasma and have unique spatial structure (Figure 1). They are initiated by applied electric fields that accelerate highly mobile electrons to energies sufficient to cause ionization [1]. This results in an electron energy distribution function (EEDF) with a high energy tail that is truncated by collisions with neutral atoms. Electron kinetics in gas discharges are particularly important because reaction rates and transport coefficients are sensitive functions of energy [2]. The aim of this work is to investigate the properties of DC gas discharges and to determine the EEDF by the Langmuir probe diagnostic.

THEORY

In general, the mathematical formulation of particle distributions is given by the Boltzmann equation [3]

$$\frac{\delta f}{\delta t} + \boldsymbol{v} \cdot \nabla_x f + \boldsymbol{a} \cdot \nabla_v f = \left.\frac{\delta f}{\delta t}\right|_c$$

For isotropic distributions, exact solutions are obtained

$$f(\mathcal{E}) = C_1 \mathcal{E}^{1/2} \exp(-C_2 \mathcal{E}^x)$$

Anisotropic distributions can be estimated by a two-term approximation

$$f(\boldsymbol{r}, \boldsymbol{v}, t) \approx f_0(\boldsymbol{r}, \boldsymbol{v}, t) + \boldsymbol{v} \cdot \boldsymbol{f}_1(\boldsymbol{r}, \boldsymbol{v}, t)$$

The EEDF can be measured for all types of distributions with Langmuir probes [4].

$$f(V) = \frac{2m}{e^2 A}\left(\frac{2eV}{m}\right)^{1/2} \frac{d^2 I}{dV^2}$$

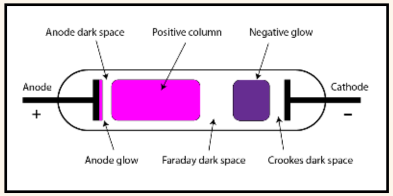

Figure 1: Schematic of glow discharge plasma.

EXPERIMENT DESIGN

The experiment apparatus was constructed from a glass tube and parallel plate electrodes. An array of four Langmuir probes were inserted through a modified cathode electrode (Figure 2) and axially spaced by 5 mm (Figure 3). Breakdown voltages of several gases were measured as a function of pressure and electrode separation (Figure 4). Images of the discharge were recorded using a USB camera and emission spectra were obtained using a spectrometer (Figure 5). The potential distribution was measured in the cathode region and an electric field calculated (see Figure 6). The EEDF was calculated from the second derivative of an IV characteristic for the probe at 20mm (Figure 7). These results were obtained for an electrode separation of 5 cm and gas pressure of 1 Torr. Argon gas was used for the spectroscopy and Langmuir probe measurements.

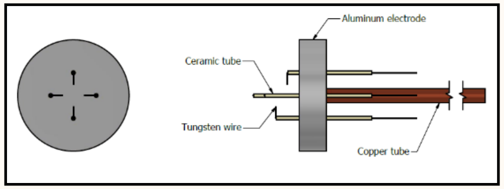

Figure 2: CAD rendering of modified cathode.

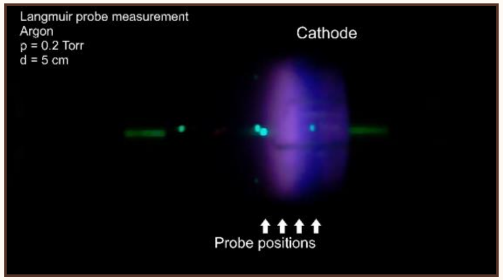

Figure 3: Image of negative glow plasma.

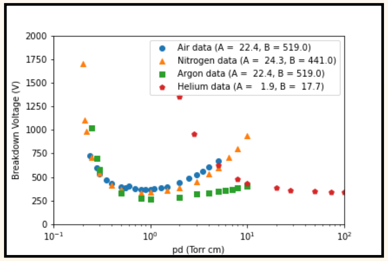

Figure 4: Breakdown voltage measurements.

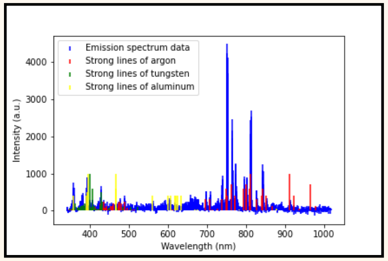

Figure 5: Spectroscopy measurements.

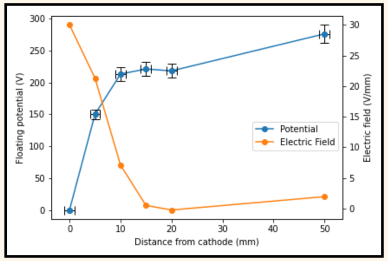

Figure 6: Floating potential measurements.

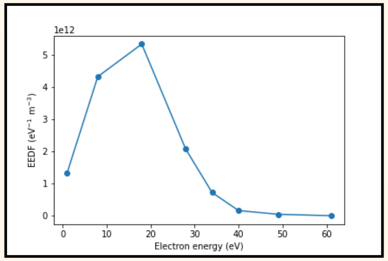

Figure 7: EEDF measurement.

DISCUSSION

The breakdown voltage results show that argon has a similar trend as air and nitrogen, but not helium. This is possibly due to similar ionization potential. The potential profile measurements show an approximately linear axial profile within the length of the negative glow. Outside of this region the potential levels off below the potential of the anode. The spectroscopy data was compared with reference data from the NIST Atomic Spectra Database to identify which elements were present in the system. The overlap of the measured lines with the reference data indicate the presence of those elements. The EEDF measurements have a clear exponential decrease as expected from the theoretical prediction. The plasma density was calculated as $9 \times 10^{14}\ \mathrm{m}^{-3}$ and the average energy as $11\ \mathrm{eV}$. The low energy part of the distribution was altered due to perturbation of the plasma by the probe.

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