Departure from Maxwellian electron energy distribution function in microwave argon plasmas at atmospheric pressure

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Optical emission spectroscopy was used to analyse the EEDF in atmospheric-pressure argon plasmas sustained by surface wave. Using emission lines from Ar >4p levels, an excitation temperature of 0.37eV was obtained from the Boltzmann plot. On the other hand, the electron temperature determined by comparing the emission intensities from Ar 4p-to-4s transitions to those predicted by a collisional-radiative (C-R) model assuming a Maxwellian EEDF yielded 1.55eV. Departure from a Maxwellian EEDF was confirmed by allowing non-Maxwellian distributions in the C-R model and obtaining a much better experimental/theoretical agreement. Moreover, the distribution yielding the best fit was consistent with the excitation temperature at low electron energies but was characterized by a high-energy tail.

1. Introduction

Surface-wave plasmas are very attractive tools to study phenomena in ionized gases because they can be sustained over a wide range of experimental conditions. In many studies reported in literature, the electron population is described by a Maxwellian Electron Energy Distribution Function (EEDF), even under atmospheric-pressure plasma conditions. In this work, optical emission spectroscopy is used to analyse possible departure from Maxwellian EEDFs in argon plasmas produced by surface waves in the microwave regime.

2. Experimental setup and data analysis

The microwave plasma was sustained at 2.45GHz in a fused silica tube (6mm ID, 8mm OD) with a surfaguide wave launcher. All measurements were recorded with an absorbed power of 500W, at 10cm downstream from the launching gap. The Ar mass flow rate was set to 0.5slm and the tube was open to ambient air. Optical emission spectra were recorded over two wavelength ranges. The first one covered the 400-700 nm range and was used to record emission lines from Ar >4p levels. Assuming Boltzmann equilibrium for these states [1], the Ar lines were used to extract an excitation temperature (T_{exc}) from the Boltzmann plot. The second range (700-900 nm) was used to analyse Ar 4p-4s transitions. The Ar lines were then fitted with a collisional-radiative model to extract the mean electron energy $\langle E \rangle$. The electron energy probability function (EEPF) was allowed to be a generalized probability function $\exp[(E/\langle E \rangle)^n]$, where the Maxwellian EEPF corresponds to n=1 and only in such a case is $\langle E \rangle$ the electron temperature T_e.

3. Results

In this study, T_{exc} was 0.37eV whereas the value of T_e obtained assuming a Maxwellian EEPF was 1.55eV. While T_{exc} most likely describes low-energy electrons (up to ~1eV), direct and stepwise excitation reactions considered in the C-R model are sensitive to both low and high-energy electrons, hence the difference. As shown in Fig. 1, departure from a Maxwellian EEDF was confirmed by decreasing the *n* parameter in the generalized EEPF function and obtaining a lower standard deviation (better agreement) between measured and simulated emission spectra. The best fit was obtained for *n*=0.6. In such condition, the EEPF displayed in Fig. 2 presents a similar trend to T_{exc} at low electron energies. However, a high-energy tail is observed, which is consistent with the higher Te value obtained with *n*=1.

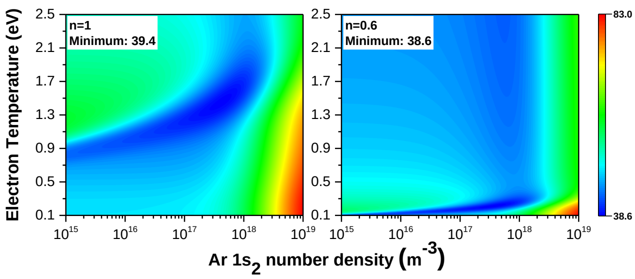

Fig. 1: Percentage standard deviation colormaps for a Maxwellian (left) and *n*=0.6 generalized (right) EEPFs

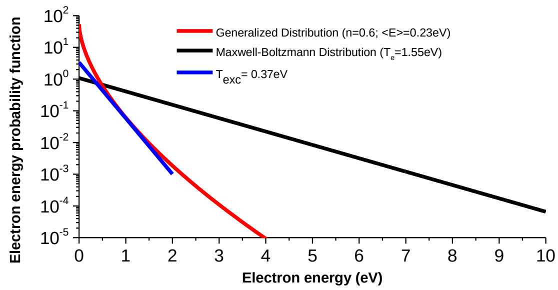

Fig. 2: EEPFs calculated from T_e, T_{exc}, $\langle E \rangle$, and n.

4. References

[1] M. D. Calzada, M. Sáez, and M. C. García, J. Appl. Phys. **88**, 34 (2000).