Non-Local Electron Energy Probability Function In A Plasma Expanding Along A Magnetic Nozzle

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Abstract: Electron energy probability functions (eepfs) have been measured along the axis of a low pressure plasma expanding in a magnetic nozzle. The shape of eepf determines the profile of the electric potential and therefore acceleration of ions. The eepf is nonMaxwellian and shows a depleted tail due to wall losses. The eepfs measured along the central magnetic field line coincide with each other after shifting energy coordinate on the value corresponding to the local electron potential energy. This demonstrates that the sum of potential and kinetic energies of the electrons is conserved thus confirming the validity of non-local approach to the electron kinetics of a low-pressure plasma expanding in a magnetic nozzle. Because the probe measures eepf, averaged over all incident electron velocity angles and measured eepfs coincide, this indirectly proves that eepf is isotropic in this plasma. This finding gives important restrictions on future theories describing plasma expanding along a magnetic nozzle.

Nomenclature

I. Introduction

In low pressure partially-ionized plasmas the electron energy probability function (eepf) is typically non-Maxwellian because electron-electron collisions are not frequent enough compared to other processes responsible for the eepf formation[1]. The eepf determines the electron pressure and ambipolar electric field and hence ion acceleration. If electrons residence time is long compared with the collision time the eepf is isotropic. If electron energy relaxation length is large compared with the plasma inhomogeneity spatial scale the eepf is function of total (kinetic plus potential) energy, because the total energy is a conserved quantity. This means that eepfs in plasma are not different functions at different locations but rather a single function for entire plasma, see Ref. [1] and references within. This has been shown for a variety of discharges in the past (ICP, CCP, ECR) but recently it was also proven for helicon discharge at low pressure. Measurements of the eepf were made along the axis of a magnetic nozzle which has the rf plasma source situated at throat with the plasma being allowed to expand freely into the expanding

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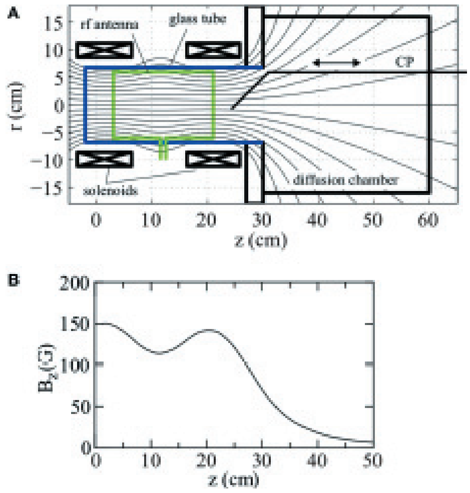

Figure 1. Schematic of the "Chi Kung" expanding magnetic field plasma experiment showing main components (CP is the rf compensated Langmuir Probe) and (B) Bz component of magnetic field along the main axis.

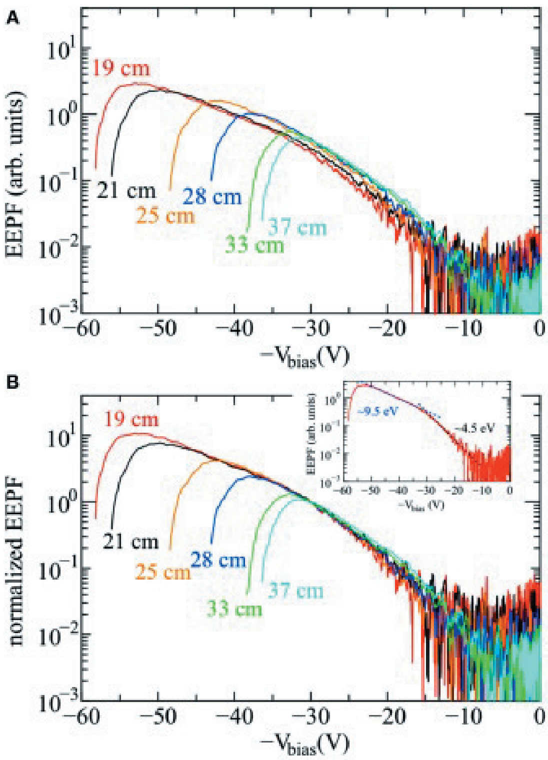

Figure 2. (A) As measured EEPFs and (B) EEPFs normalized at Vbias = 30 V for increasing axial positions (from z = 19–37cm);the inset on (B) is the EEPF measured at z = 19 cm showing the two Maxwellian fits (dotted lines) for the trapped (9.5eV) and escaping (4.5eV) electrons; the break energy is defined as the intersection between the two fits.

magnetic field as shown in Fig.1. Measurements of the eepfs are performed using an axially movable rf-compensated Langmuir probe (CP) inserted via a vacuum port on the downstream end vacuum flange. The eepf can be obtained from the second derivative of the current-voltage (I_p/V_{bias}) characteristics of the Langmuir probe using the well-known Druyvesteyn method implemented here by an analog differentiation technique. The "as measured" axial eepfs are shown on Figure 2A: the local plasma potential Vp is given by the zero-crossing point of the second derivative and the energy of the electrons is given by $\varepsilon = -V_{bias} + V_p$ where V_{bias} is the voltage applied to the Langmuir probe. The eepfs on Figure 2A are plotted by keeping the same X label range of Vbias = 0–60 V to show that Vp at z = 19 cm is 58 V decreasing to Vp =32V at z = 37 cm.

Further details and description of experimental set up are given in Ref. 2.

The results of the measurements suggest that the trapped electrons are indeed isotropic and the Langmuir probe is producing reliable measurements and eepfs can be described by a single function of total energy.

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