Langmuir probe characteristics in the presence of supra-thermal electrons generated by a lower hybrid grill*

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1 Introduction

We present a self-consistent description of a presheath plasma and an interpretation of Langmuir probe characteristics in the presence of non-Maxwellian supra-thermal electrons. The supra-thermal electrons are here generated in the vicinity of a lower hybrid (LH) grill [1,2] and flow along magnetic field lines to a Langmuir probe. The presheath plasma is bounded by the sheath-presheath interface at one end and plasma at the other end. We study this plasma edge problem computationally using a quasi-neutral particle-in-cell (QPIC) code [3,4]. The LH grill - edge electron interaction is treated by a Monte-Carlo method described in [7]. For conditions of the Tore Supra edge plasma and LH grill (f_{LH}=3.7 GHz, E_0=3 kV/cm, wave-guide+septum width=1.05 cm) the pre-sheath remains quasi-neutral throughout with an appreciable density depression and temperature increase in the grill region, in agreement with previous test electron simulations [7]. Near the wall, a precipitous density drop is caused by ion loss. A proportional number of most energetic electrons are allowed to reach the wall while maintaining equal particle flows. This allows inferring the floating potential V_f. For typical Tore Supra LH grill conditions we obtain V_f=-17.7 T_{e0}, compared with V_f =-1.45 T_{e0} at thermal conditions (we use ion-to-electron mass ratio m_i/m_e=200). Other results such as the ion and electron distribution functions and their velocity moments are discussed and it is shown that most assumptions made in the standard interpretation of measured probe V-I characteristics are violated.

2 Benchmarking the quasi-neutral particle-in-cell (QPIC) code

A particle-in-cell (PIC) simulation technique suitable for describing phenomena evolving on time and spatial scales much shorter than respectively $1/\omega_{pe}$ and λ_D was proposed by Joyce et al.[3]. In this method, which we henceforth refer to as quasi-neutral PIC or QPIC, the self-consistent electrostatic field E_s is not determined from the Poisson equation but rather at each time step of the simulation E_s is calculated from the electron momentum equation and the requirement of quasi-neutrality. The QPIC technique is thus suitable where the governing temporal and spatial scales in the problem do not allow large departures from quasi-neutrality, which allows cell sizes much large than the Debye length and time steps much larger than the electron plasma period. The QPIC approach significantly reduces the simulation CPU time and mainly avoids swamping of the physically induced charge separation by statistical fluctuations in the electron and ion densities. The QPIC code as well as the specific pre-sheath particle loss and gain processes were discussed and tested in [4], where excellent agreement was obtained with theoretical results for a presheath with Boltzmann electrons [5] and for a presheath with a double-Maxwellian electron distribution [6].

3 Lower hybrid grill in the presheath

Conditions specific to the presheath plasma immediately indicate the difficulty of carrying out standard PIC simulations: the edge plasma Debye length is of the order of 10^{-5}m, while the required simulation region length varies from 10-100m depending on the plasma parameters and probe size. The characteristic perturbation length of the probe is $L_p=a^2c_S/D_\perp$, where a is the probe diameter, c_S is the sound speed, and $D_\perp$ is the perpendicular diffusion coefficient. Hence at least 10^5-10^7 cells would be necessary. By contrast, the presheath QPIC simulations of Ref. [4] were carried out with 100 cells, i.e. with cell sizes Δz of the order of meters, and time steps $\Delta t \leq \Delta z/v_e$. The flux tube connected to the probe also passes in front of a LH grill which is situated between $2.5 \leq z \leq 3.0$ in Figs. 1 and 2. We use a Langevin velocity space diffusion description of the localized heating of the electrons in front of the LH grill [7].

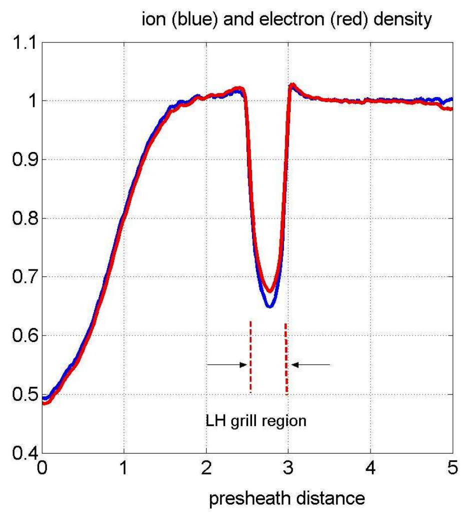

Fig. 1 *Ion and electron density along the presheath with LH power. Distance is normalized to the probe perturbation length*

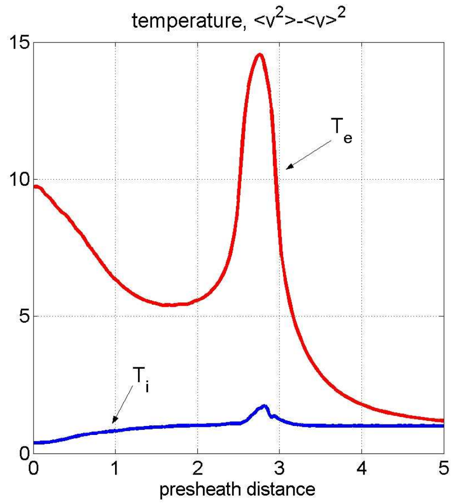

Fig. 2 *Ion and electron temperature along the presheath with LH power.*

The boundary conditions for the simulation are a Maxwellian thermal inflow at the plasma side (right hand boundary) and in the perpendicular direction to compensate for parallel and perpendicular particle outflow, and equal ion and electron flows to the wall (left hand boundary). All ions reaching the wall are absorbed there, while the electron inflow is at each time step adjusted to satisfy equal inflow condition. The wall is thus maintained at floating potential and effectively replaces the physical non-neutral sheath. The thin wall-presheath interface is here expanded through a stretching transformation of the spatial variable. Velocities are normalised to the Bohm velocity and energies to the equilibrium plasma temperature T_{eo}. In Fig. 1, the density drop at the wall is due to ions loss. The density drop in the LH grill region is caused by rapid outflow of the LH-generated hot electrons, shown in Fig.2. The electron temperature increases toward the wall together with the sheath potential which acts to reflect the less energetic electrons. More information follows from the distribution functions of Fig. 3:

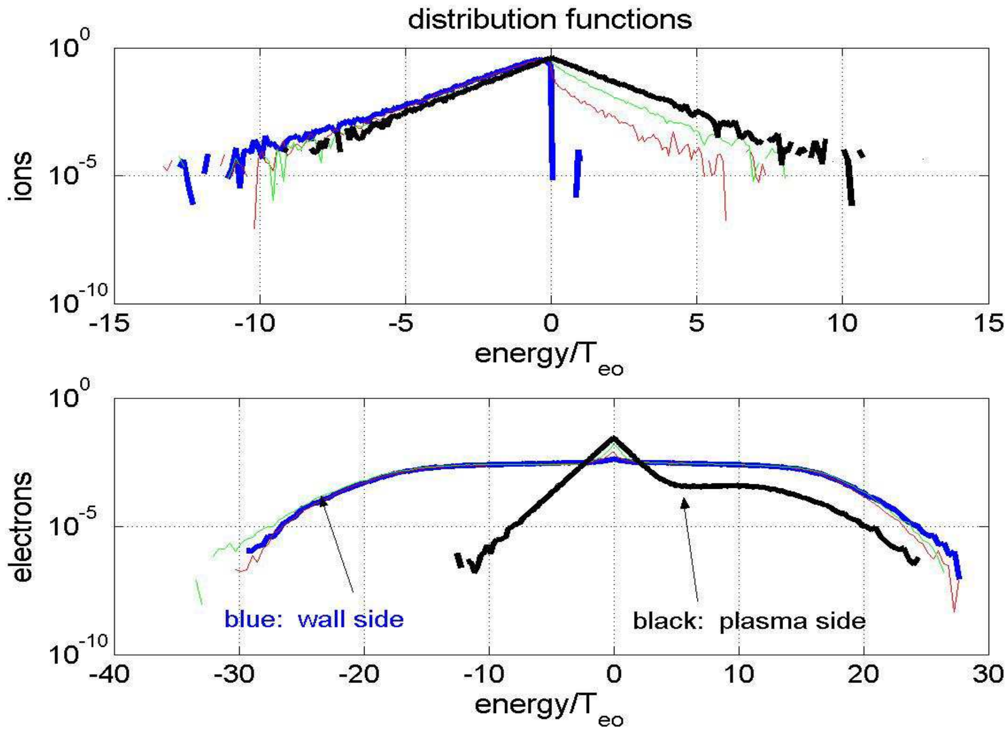

Fig.3 *Ion and electron distributions as function of normalised energy*

The ion distribution at the plasma side is thermal Maxwellian, left-going electrons are also thermal Maxwellian, but the right-going electrons generated in the LH grill region are suprathermal and non-Maxwellian. At the wall the ion distribution is one-sided since all incoming ions are absorbed. In contrast, the electrons are suprathermal and strongly non-Maxwellian. We see that at energy of about 15 T_{eo} the slope of the electron distribution breaks and the electron population rapidly declines, indicating that beyond this energy the incoming electrons are no longer reflected by the potential barrier. This limiting value of energy is actually the floating potential. Finally, simulated Langmuir probe characteristics are shown in Fig. 4:

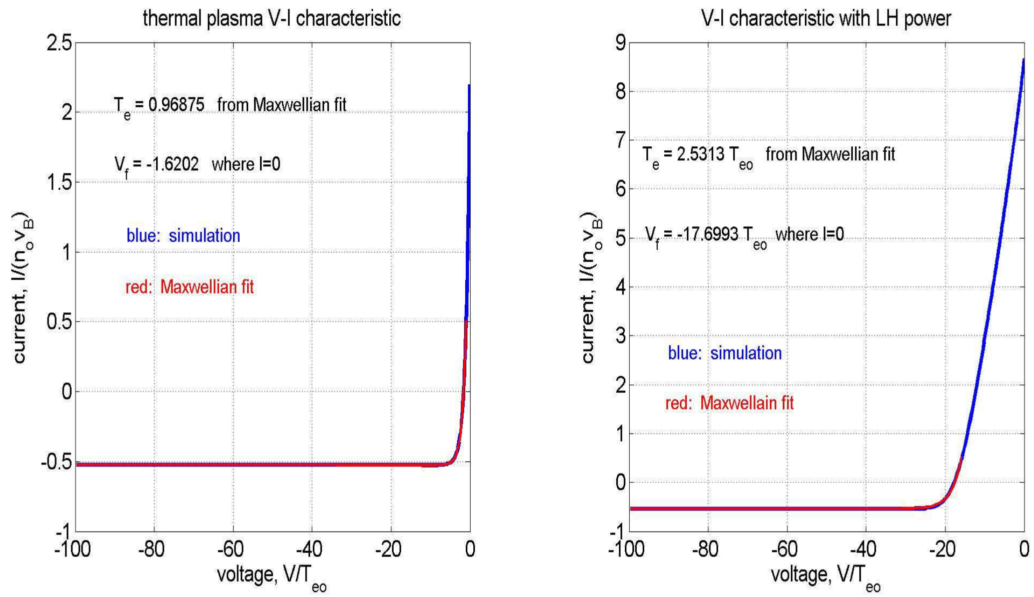

Fig. 4 *Computed Langmuir probe characteristics for a plasma without and with LH power.*

An exponential function was fitted to the simulated characteristics in the same way that is done for experimental data at Tore Supra. Current of magnitude greater than the ion saturation current is excluded from the fit, so that the fitted temperature corresponds to a highly restricted energy range in the immediate vicinity of the floating potential. Both the fitted floating potential and the electron temperature are sensitive to the details of the electron distribution function, so it is doubtful that anything other than the presence of fast electrons can be inferred. In order to obtain quantitative information, another diagnostic such as a retarding field analyzer would be needed to be employed.

References

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