

Potential formation in front of a floating, planar, electron emitting electrode studied by particle in cell simulations

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Introduction

The study of electron emitting surfaces is of great importance for plasma physics. Understanding the potential formation in front of an electron emitting solid surface in contact with a plasma is important for various applications – from emissive probes to implications in the field of fusion. For instance the divertor in ITER is expected to reach such high temperatures that it could become strongly emissive [1].

It is generally accepted that when electron emission from a floating electrode is gradually increased, the floating potential increases also, until so-called space charge limited emission is reached. At that point a potential dip (virtual cathode) is formed in front of the electrode, which then prevents further emission of electrons from the electrode. It was believed for a long time that further increase of electron emission only increases the depth of the potential dip, while the floating potential remains more or less constant – one speaks about saturation of the floating potential. Only recently Campanell [3] predicted a possibility that at strongly increased electron emission the electrode might start to float above the plasma potential – i. e. it would become positively biased with respect to plasma. Such structure was called inverted sheath. Experimental observations of inverted sheaths have in fact not yet been confirmed with certainty. In ref. [4] a short overview of literature is made, where inverted sheaths might have been observed, but the authors were not aware of it. In this work potential formation in front of a planar, floating, electron emitting electrode is investigated using a 1d3v particle in cell code BIT1 [2]. Plasma is created by volume ionization in the entire space between two planar electrodes. The right electrode is at zero (reference) potential, while the left electrode is floating and emits electrons. It is assumed that the flux of emitted electrons is a given quantity. This corresponds to Richardson emission from a hot metal electrode. The distribution function of the emitted electrons is assumed to be a drifting Maxwellian.

Results of simulations

The system is 5 cm long and divided into 20000 cells. So the length of 1 cell is 2.5 microns. Also the time step of the simulation is very short $\Delta t = 2.5 \times 10^{-13}$ s. In this way it is taken care that there is a sufficient number of cells per Debye length and sufficient number of time steps per electron plasma period even in the case of highest plasma densities obtained. For the simulations code BIT1 [2] is used. From its beginnings this code was designed for fusion oriented simulations of the scrape-off-layer plasma. A large number of binary, atomic and plasma-wall interaction microscopic processes can be included in the simulations. In this work a collisionless discharge is simulated. Electron emission from the left electrode is

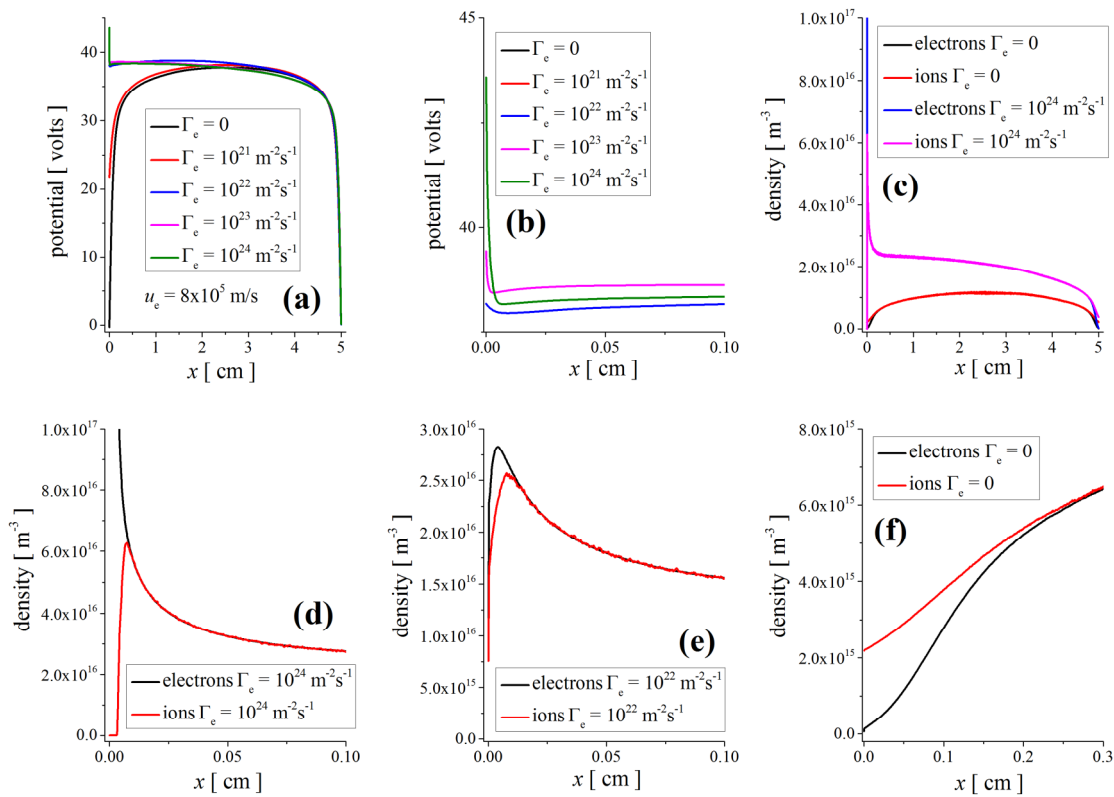


Figure 1: Simulation profiles obtained with weaker source and zero ion temperature.

prescribed. This electrode is electrically floating with respect to the right electrode, which is grounded – at the zero potential. The code uses physical units, so actual masses and charges of particles are used. Particle temperatures are given in eV, potentials in volts, velocities in m/s particle fluxes in particles/m²s, energy fluxes in W/m² and so on. In this work plasma is composed of singly charged deuterium ions and electrons. In Fig. 1 an example of the simulations results is shown. Electrons are Maxwellian with a temperature $kT_e = 10$ eV, while ions are born cold and at rest. In Fig. 1 a weak source $S = 5 \times 10^{21}$ ion-electron pairs created per m³ and per second. In the absence of any emission a symmetric potential and density profile

is formed (plots (a) and (c)), with potential in the center about 35 V and density around 10^{16} m^{-3} . Then electron emission is started from the left electrode. Electrons are emitted with a drifted Maxwellian velocity distribution, with temperature $kT_{em} = 0.318 \text{ eV}$. This corresponds to the melting temperature of tungsten 3695 K. In code BIT1 emission of electrons must be given in the units of flux, i. e. number of electrons leaving the electrode per m^2 and per s. Highest theoretical Richardson emission from tungsten at the melting point is $6.37 \times 10^6 \text{ A/m}^2$. When this is divide by elementary charge the highest theoretical flux of emitted electrons is obtained $\Gamma_e = 3.97 \times 10^{25} \text{ m}^{-2}\text{s}^{-1}$. The drift velocity of electrons $u_e = 8 \times 10^5 \text{ m/s}$ is selected arbitrarily. Emission fluxes are increased gradually from $\Gamma_e = 10^{21} \text{ m}^{-2}\text{s}^{-1}$ to $\Gamma_e = 10^{24} \text{ m}^{-2}\text{s}^{-1}$. At $\Gamma_e = 10^{21} \text{ m}^{-2}\text{s}^{-1}$ only the floating potential of the left electrode increases, but the potential profile stil decreases monotonically. At $\Gamma_e = 10^{23} \text{ m}^{-2}\text{s}^{-1}$ the inverted sheath is clearly formed.

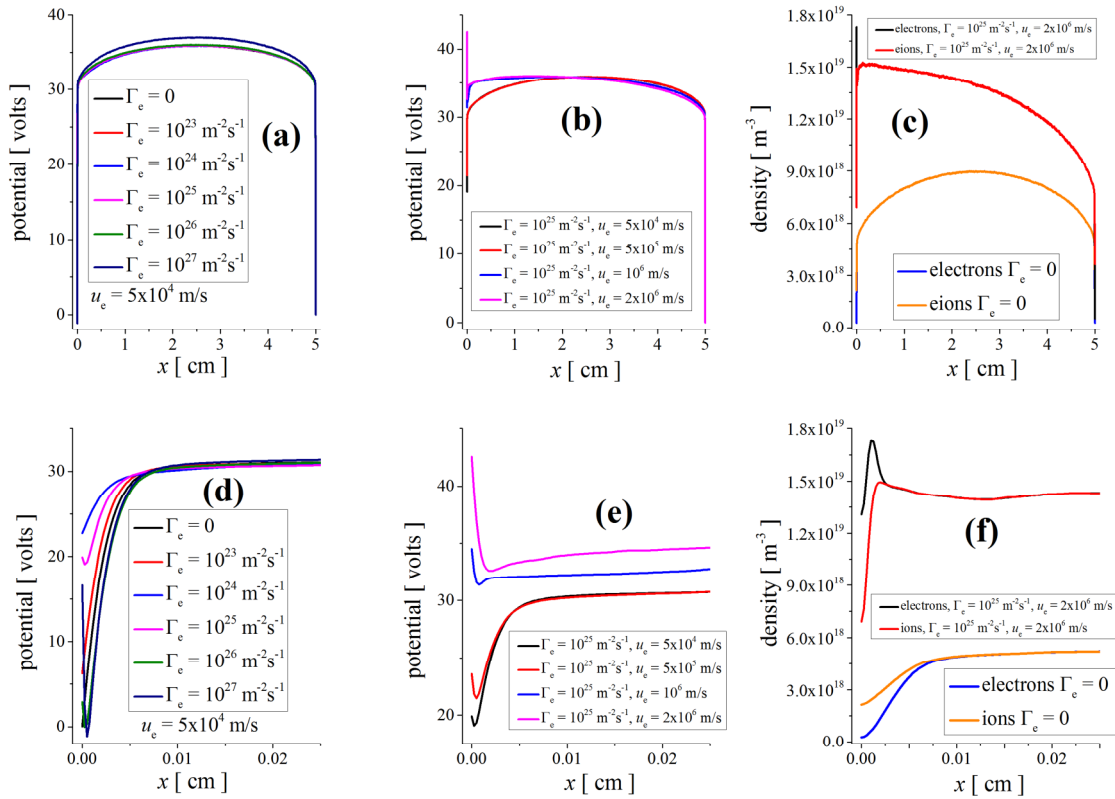


Figure 2: Simulation profiles obtained with stronger source and ion temperature $kT_i = 10 \text{ eV}$.

Floating potential of the left electrode exceeds the highest plasma potential between both electrodes. At $\Gamma_e = 10^{22} \text{ m}^{-2}\text{s}^{-1}$ an interesting structure is formed, which deserves further investigation. In plot (e), where density profiles close to the left electrode are shown, it can be seen that there is negative space charge everywhere in the sheath and that the sheath is much thinner than in the case of zero emission – graph (f). In plot (d) the “classical” inverted sheath

profile, as predicted by Campanell [3] can be seen, where the ion density in the sheath drops to zero and the sheath is much thinner than the classical sheath in plot (f).

In Fig. 2 another example of simulation profiles is shown. This time the source is 1000 times stronger, $S = 5 \times 10^{24} \text{ m}^{-3} \text{ s}^{-1}$ and the source ion temperature is $kT_i = 10 \text{ eV}$. In the absence of emission a symmetric profile is formed with plasma potential in the center around 35 V and density around $9 \times 10^{18} \text{ m}^{-3}$, which is close to the density in the scrape-off layer of a medium tokamak. Flux of emitted electrons from the left electrode is again gradually increased. Emitted electrons are drifted Maxwellian with temperature $kT_{em} = 0.318 \text{ eV}$ and drift velocity $u_e = 5 \times 10^4 \text{ m/s}$. Even at $\Gamma_e = 10^{27} \text{ m}^{-2} \text{ s}^{-1}$, which is above the theoretical limit for tungsten electrode at the edge of melting, sheath is still space charge limited (plots (a) and (d)). Then $\Gamma_e = 10^{25} \text{ m}^{-2} \text{ s}^{-1}$ is taken and u_e is gradually increased (graphs (b) and (e)). At $\Gamma_e = 10^{25} \text{ m}^{-2} \text{ s}^{-1}$ and $u_e = 2 \times 10^6 \text{ m/s}$, inverted sheath seems to be formed, but the density profile (plot (f)) shows that this is still some kind of transition between space charge limited and inverted sheath – similar as Fig. 1 (e).

Conclusions

Potential formation in front of a floating electron emitting electrode has been studied by PIC simulation. It has been shown that at increased plasma density and ion temperature – plasmas similar to those in the scrape-off layer of a medium tokamak – it is very difficult to achieve inverted sheath configuration. In fact until now it has been achieved only with extreme emission parameters, which can not be realized in an experiment. Future investigations should be focused to the role of kT_i and u_e .

References

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