Effects of Asymmetric Secondary Emission on Plasma Properties in Hall Thruster Acceleration Channel

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The plasma-wall interaction plays a major role in the performance of the Hall thrusters. There have been sufficient experimental and theoretical evidence that strong secondary electron emission (SEE) from the channel walls affects thruster operation. SEE enhances the heat losses to the walls and increases electron conductivity, which, consequently, degrades thruster performance [1]. In low-pressure devices like Hall thrusters, the electron mean free path exceeds the size of the system; therefore, the secondary electrons penetrate the bulk plasma and exit to the opposite wall without undergoing collisions. Thus, SEE fluxes affect the charged particle flux balance on walls far from their origination source. As a result, the sheathes at opposite walls are not independent of each other due to exchange of SEE electron fluxes. In this paper, the emission and recollection of electrons by walls is studied using a 1-D model with the asymmetric secondary emission from the inner and outer walls of the Hall thruster channel. Schematic of simulation setup is shown in Fig.1. The SEE fluxes on the inner and outer walls of Hall thruster might be asymmetric due to specially designed wall materials, asymmetric wall erosion, mirror or centrifugal forces [2,3]. Here, the right-wall SEE yield model is based on the boron nitride and the left-wall SEE yield is proportionally reduced from the boron nitride value with a scaling factor to study effect of asymmetry. Plasma properties in a typical Hall thruster channel were simulated making use of particle-in-cell EDIPIC code [4].

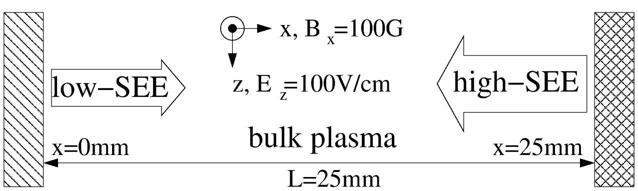

Fig.1 Schematic of the 1D model

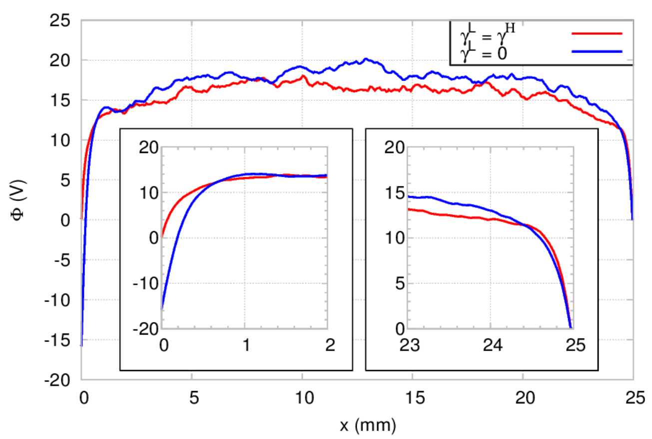

Fig.2 Potential profiles obtained in particle-in-cell simulations. Red lines correspond to symmetric case, blue lines correspond to asymmetric case with no emission from the left wall.

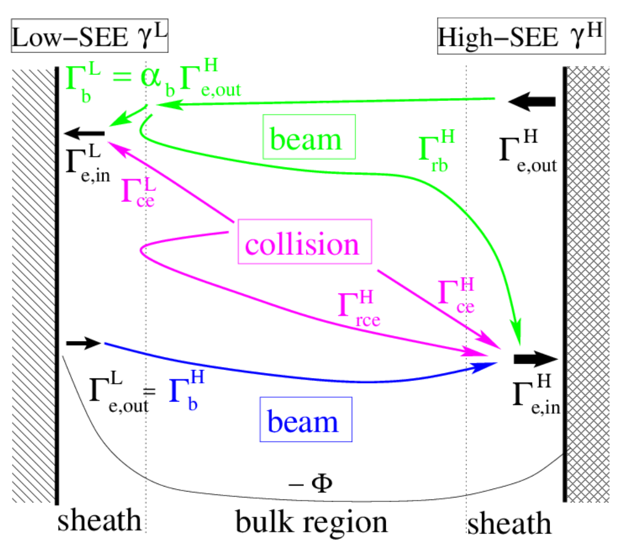

Fig.3 Schematics of the electron fluxes in the Hall thruster channel. The subscript 'ce' denotes bulk electrons ejected to walls by collisions. 'b' denotes beam electrons originated from walls due to SEE. 'rb' or 'rce' denotes the beam or collision-ejected bulk electrons that are reflected by sheath.

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The potential profile becomes significantly asymmetric with decrease of the SEE yield of the left wall as compared to the right wall, as shown in Fig.2. An apparent consequence of the potential profile asymmetry is that, a large proportion of beam electrons moving toward the left wall are reflected by the left sheath. In the limiting case of no SEE from the left wall, the majority of incident electrons toward the right wall are electrons originated from the right wall and reflected from left sheath, and not the SEE electrons originated from the left wall, as illustrated in Fig.3. Simulations results for the sheath potential near the right wall show that the sheath potential (difference between the wall and plasma potential) is almost constant ≈18V and is independent of emission from the left wall. Change in the SEE at the left wall strongly affects the sheath potential at this wall. The analytic relation between the wall potentials and the two wall SEE yields is derived.

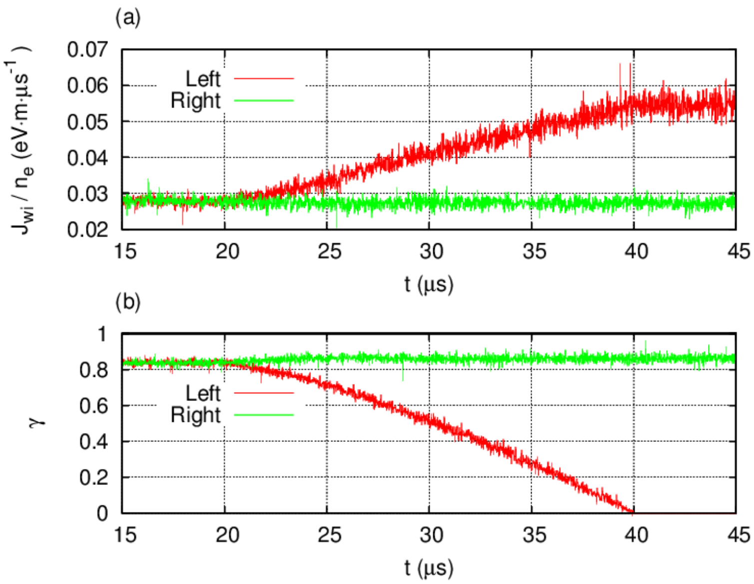

Fig.4 The evolution of (a) ion energy flux on the walls and (b) secondary emission yields. The ion energy flux is divided by the average electron number density of the whole system to eliminate the effect of electron density decreasing.

Surprising effect of the SEE asymmetry is that it leads to increase of ion energy loss to thce walls due to increase of the sheath potential near the wall with smaller emission. In the symmetric configuration, SEE may not affect the wall potential and the energy of incident ions, because SEE fluxes from opposite walls cancel each other [5]. However, in the asymmetric case, the ions are accelerated to higher energy by the larger sheath potential drop, while their flux is almost unchanged. Fig. 4 shows the time-dependent evolution of ion energy flux to the walls. The increase of ion energy flux is caused by SEE asymmetry and is proportional to the sheath potential increase.

References

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