# Origins of non-uniformity of plasma fluxes over emissive wall in low temperature plasma

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A spatial non-uniformity of electron and ion fluxes on surfaces in plasma devices can be provoked by various factors, for example, a non-planar surface topology, difference in the electron emission yield of materials in the segmented surface or presence of an oblique external magnetic field. In these cases, feedback between plasma and surface structure (through the non-planar sheath) can lead to an essential modification of the surface during device operation and a drastic change of all plasma characteristics.

In this paper, origins of spatial modulation of stationary electron and ion currents to the wall in discharge plasma with/without magnetic field at low gas pressure are studied in the experiments and 2D PIC MCC simulations. A non-uniformity of ion and electron fluxes to the wall is induced a) a non-planar topology on the emissive wall, b) a difference in the secondary electron emission yields of materials in segmented wall or c) an inclination of the external magnetic field.

For the cases a) and b), the transition in the sheath structure (from a developed sheath to a collapsed one) enforces the modulation of the ion and electron currents over the grooved or segmented surfaces. The experimental and theoretical studies of the plasma-emissive wall sheath transition were carried out with the hexagonal boron nitride wall samples grooved with the characteristic size of 1 mm and 5mm, which is about of the Debye length. In kinetic simulations, this phenomenon is analysed in terms of the electron and ion energy distribution functions.

**Case a).** In the experiment, a multidipole plasma device shown in Fig.1 is used for study of plasma-emissive wall interaction. The cylindrical plasma chamber has a radius of 30.5~cm and a height of 91~cm. The chamber is grounded and has a low secondary electron emission yield. The direct current discharge glows at P=0.1 mTorr in argon. The electrons emitted from a tungsten filament (F in Fig.1) are accelerated crossing the cathode sheath in the direction of the wall material sample with machined grooves (W in Fig. 1). These electrons form almost a monoenergetic beam with the energy corresponding to the cathode voltage U, which varies from -60 V to -350 V.

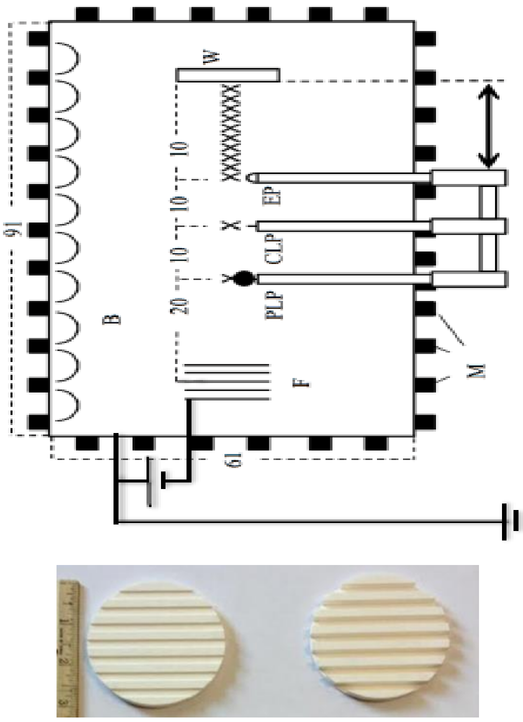


Figure 1. Sketch of plasma cell, F = filaments, M = magnets, B= magnetic field, PLP = planar Langmuir probe, EP = emissive probe, W= wall material sample.
Below: wall sample made from hBN material with machined grooves with a depth of 1 mm (left) and 5 mm (right).

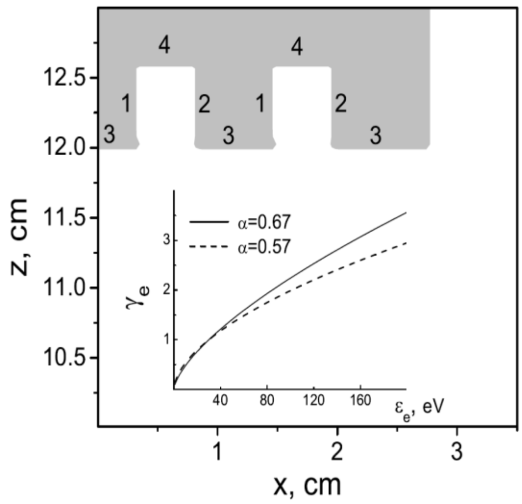


Figure 2. The geometry of grooves in simulations. 1, 2, 3, 4 show the different fragments of grooves for separate calculation of floating potential. Insert shows the SEE coefficient for hBN as a function of electron energy for different α.

In Fig. 2, a part of calculation domain near the sample with grooves of 5 mm wide and 5 mm depth is shown. In simulations, the wall material sample has four identical trenches, but in Fig. 2, there are only two grooves shown, since x=0 is the axis of symmetry. Since the BN-sample is under the floating potential the total current on it $j_{total}$=0. For the grooved sample the floating potential is calculated solving the balance equation for $j_{total}$ separately for four different surface fragments shown in Fig. 2: for left (1) and right (2) sides of trenches, for front surface (3) and for trench bottom (4). With increasing U, the sheath transition happens near BN-wall sample at some critical voltage $U_{cr}$. In Fig. 3, the potential drop φs between the bulk plasma and electrically isolated sample is shown for cases of grooved and planar surfaces. As seen in Fig. 3, both measured and calculated potential drops exhibit an abrupt transition from the developed to collapsed sheath types. The non-uniform distribution of the electric potential over the grooved surface focuses the electron current to the front fragments of grooves and the ion current inside of grooves (see for details [1]).

The energy distributions of ions calculated on the front and bottom surfaces of grooves are shown in Fig. 4 for U = -350 V, for the spatial distribution of ion current density ji shown in Fig.5. The energy of ions approaching the front surface ranges from 20 to 50 eV, whereas the energy of ions on the bottom is (100-120) eV. It is seen in Fig.5 that the ji is much higher at the bottom of grooves compared to the front surface one.

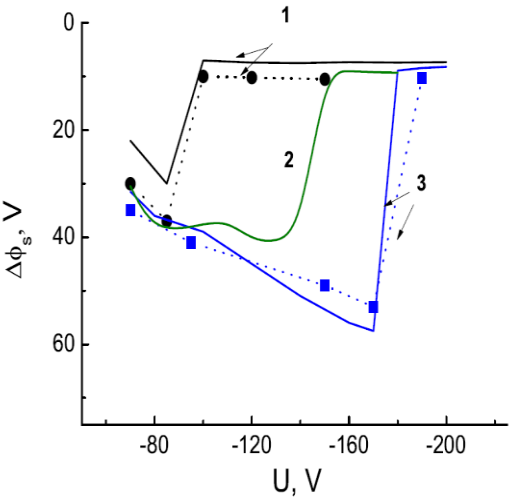


Figure 3. Potential drop near BN-wall sample as a function of applied voltage for planar (1) and grooved surfaces with a depth of 1 mm (2) and 5 mm (3). Experimental data (solid lines) and calculations (symbols).

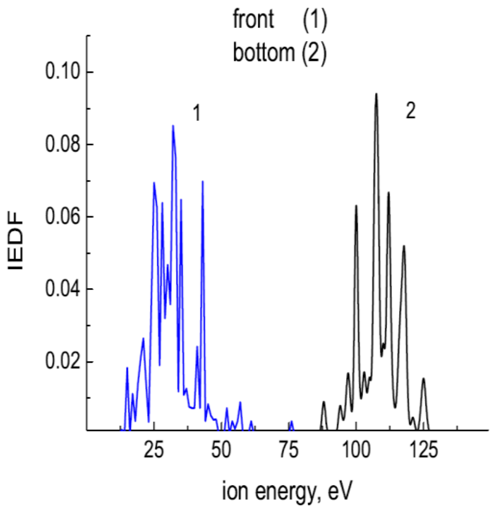


Figure 4. Energy distribution functions of ions approaching the front (1) and bottom (2) segments of trenches for U =-350 V.

**Case b).** In simulations, we found that the sheath near the segmented planar sample looks like in the case of the grooved one and has a higher $U_{cr}$ for the transition compared to the planar sample. In Fig.6, the spatial potential distribution next to the segmented planar sample is shown for the case of U > Ucr. The dark grey rectangles denote a model material with four times smaller secondary electron emission coefficient.

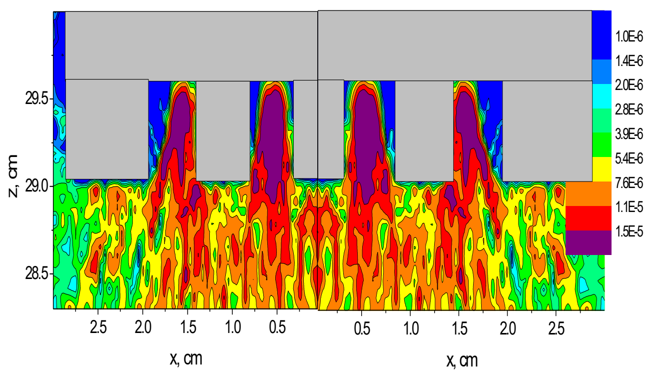


Figure 5. Spatial ion current density distribution (A/cm2) near the surface with grooves of 5 mm wide and 5 mm depth for U = - 190 V.

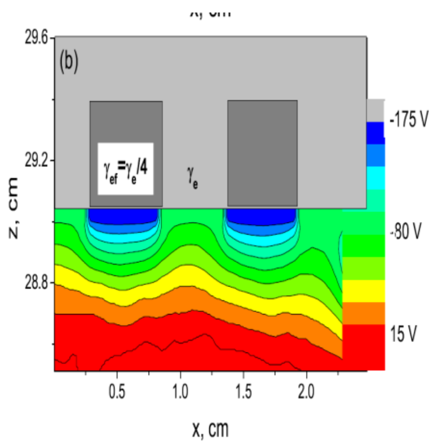


Figure 6. Spatial potential distribution for U = -330 V (b) near the segmented planar sample.

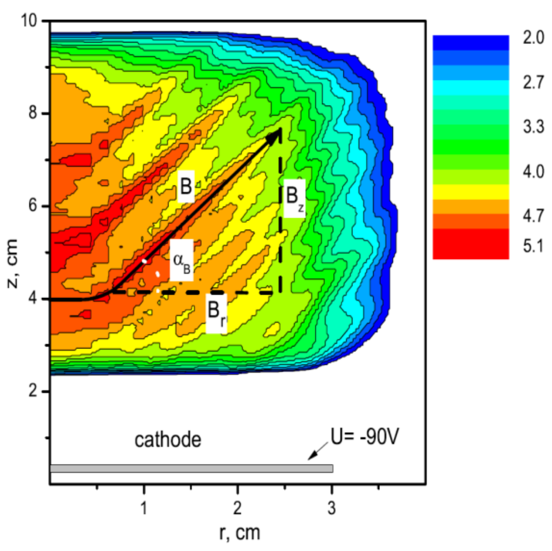


Figure 7. Spatial potential distribution in the cylindrical model plasma chamber. B denotes the magnetic field.

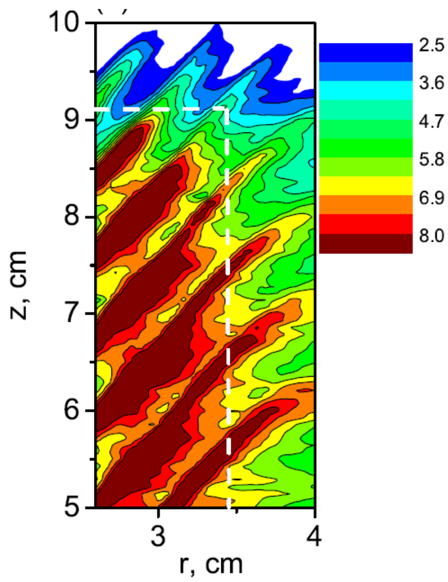


Figure 8. Spatial distribution of radial component of ion current density for B=100 G, $\alpha_B$= 65° and $T_e$=5 eV.

**Case c).** An external oblique magnetic field applied to low-pressure discharge plasma provokes the stratification of discharge plasma (see for details [2]), which causes a modulation of ion and electron currents over the wall surface. To describe this effect of the rearrangement of discharge plasma in the electromagnetic field the system of equations including Boltzmann equations for the distribution functions for electrons and ions and Poison equation for the electric potential distribution was solved with PIC MCC method. In Fig, 7 and 8, the calculated spatial distribution of potential and ion current are shown. The white lines in Fig.8 denote the approximate boundary between the bulk plasma and wall sheath. In the quasineutral plasma, the ion current is oriented along $n_i$-ridges, but within the wall sheath, the $j_i$ turns to the direction normal to the wall due to a stronger electric field.

In conclusion, in the experiment and kinetic simulations, we have considered the origins of appearance of a spatial non-uniform distribution of ion and electron currents to the wall of plasma chamber at low gas pressure.

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