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Transition in sheath structure near emissive grooved surface in discharge plasma controlled by electron beam

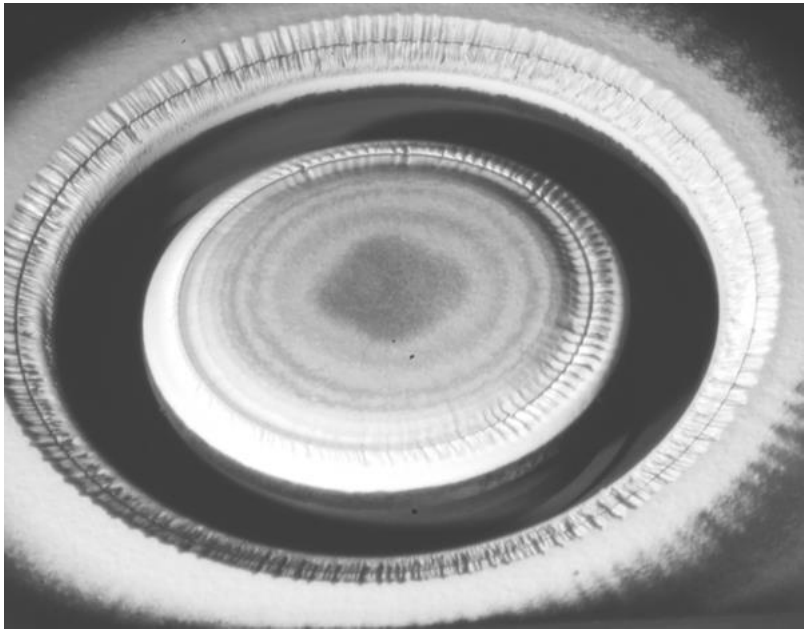
Irina Schweigert[1],
T. S. Burton[2], G.B. Thompson[2]
S.J. Langendorf[3], M.L.R. Walker[3]
M. Keidar[1]

[1] The George Washington University, Washington DC
[2] The University of Alabama, Tuscaloosa, AL
[3] Georgia Institute of Technology, Atlanta, Georgia

Plan

- Motivation
- Experimental setup
- Wall material samples
- Theoretical model
- Transition in sheath structure near emissive grooved surface
- Comparison of transition for flat and grooved emissive surface
- Conclusion

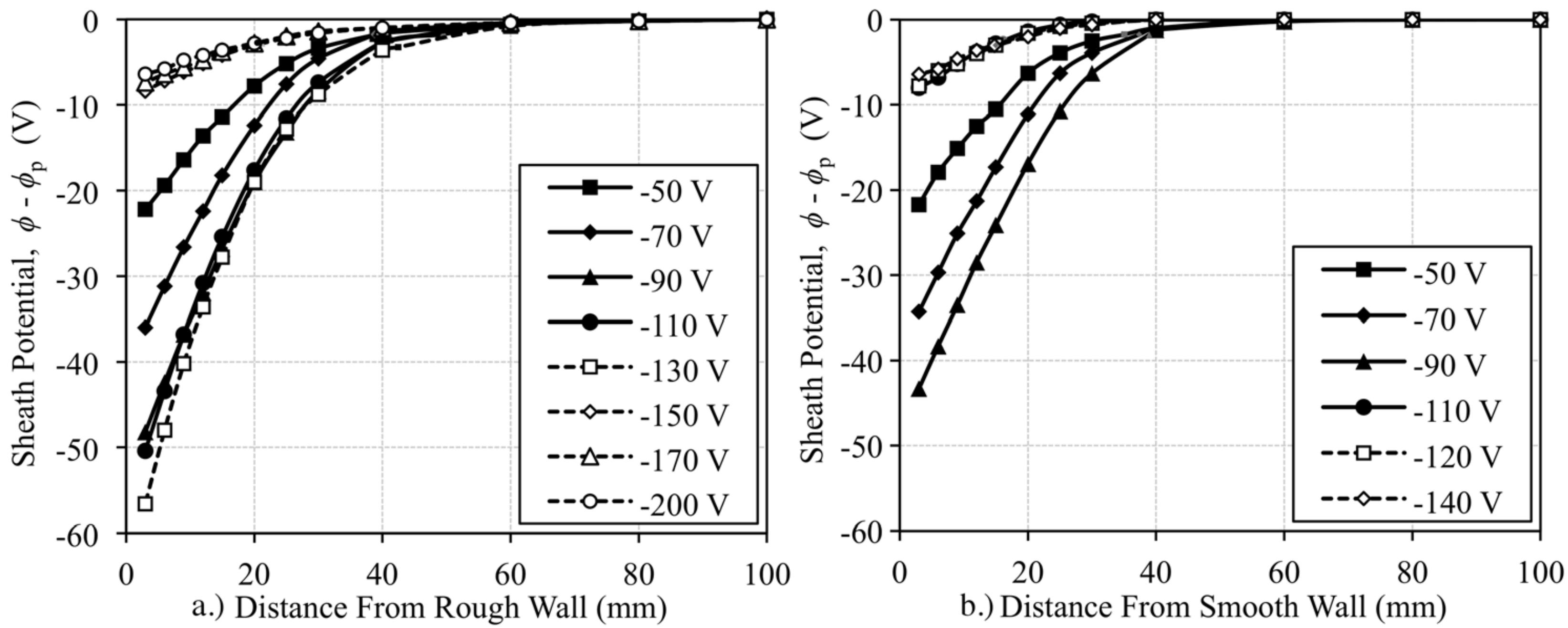
Motivation



Hall thruster life test. Figure shows a detailed photograph taken with the optical system after 10,400 hrs of operation.

De Grys, Mathers, Welander, Khayms, Demonstration of 10,400 Hours of Operation on 4.5 kW Qualification Model Hall Thruster, 46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference Exhibit, AIAA 2010-6698, July 2010.

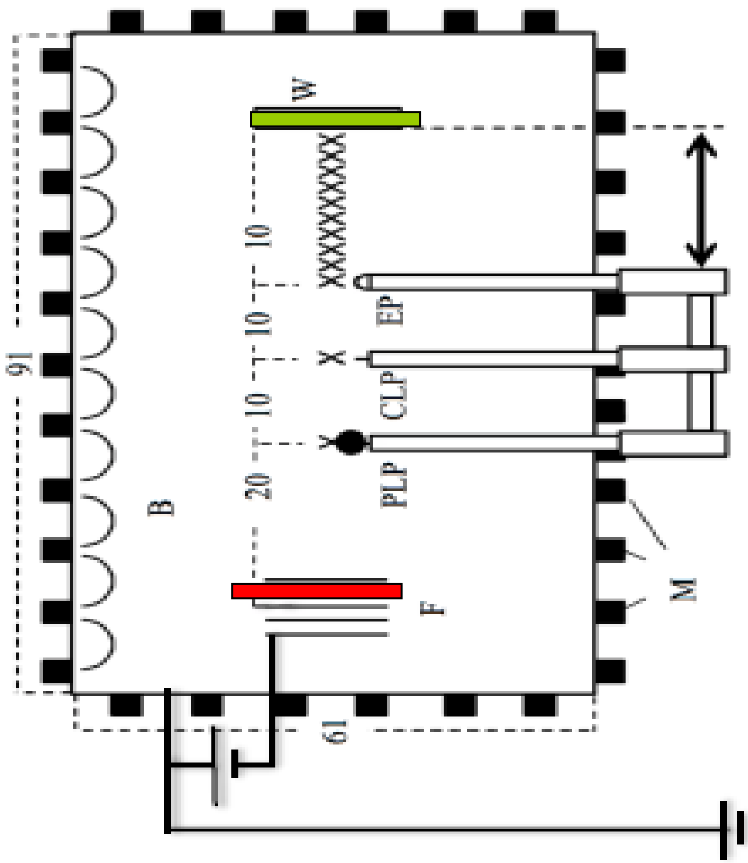
Motivation



Using different metallographically-polished hBN surfaces, the different types of plasma sheath potential were observed for the cases of smooth or rough surfaces.

Langendorf, Walker, Physics of Plasmas 22 (3) 2015

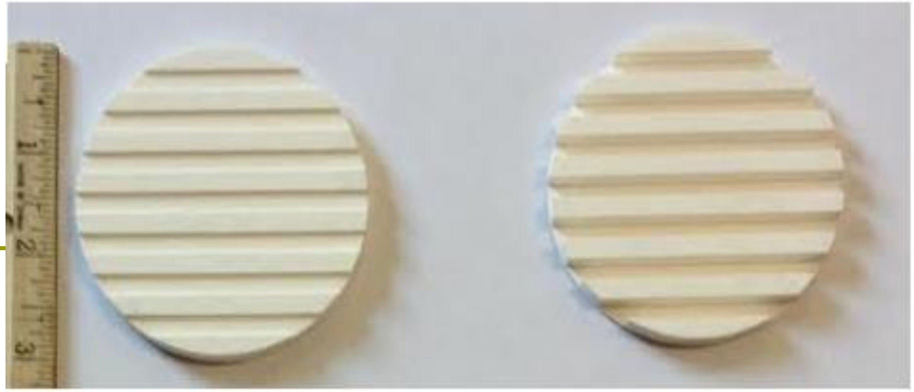
Experimental setup



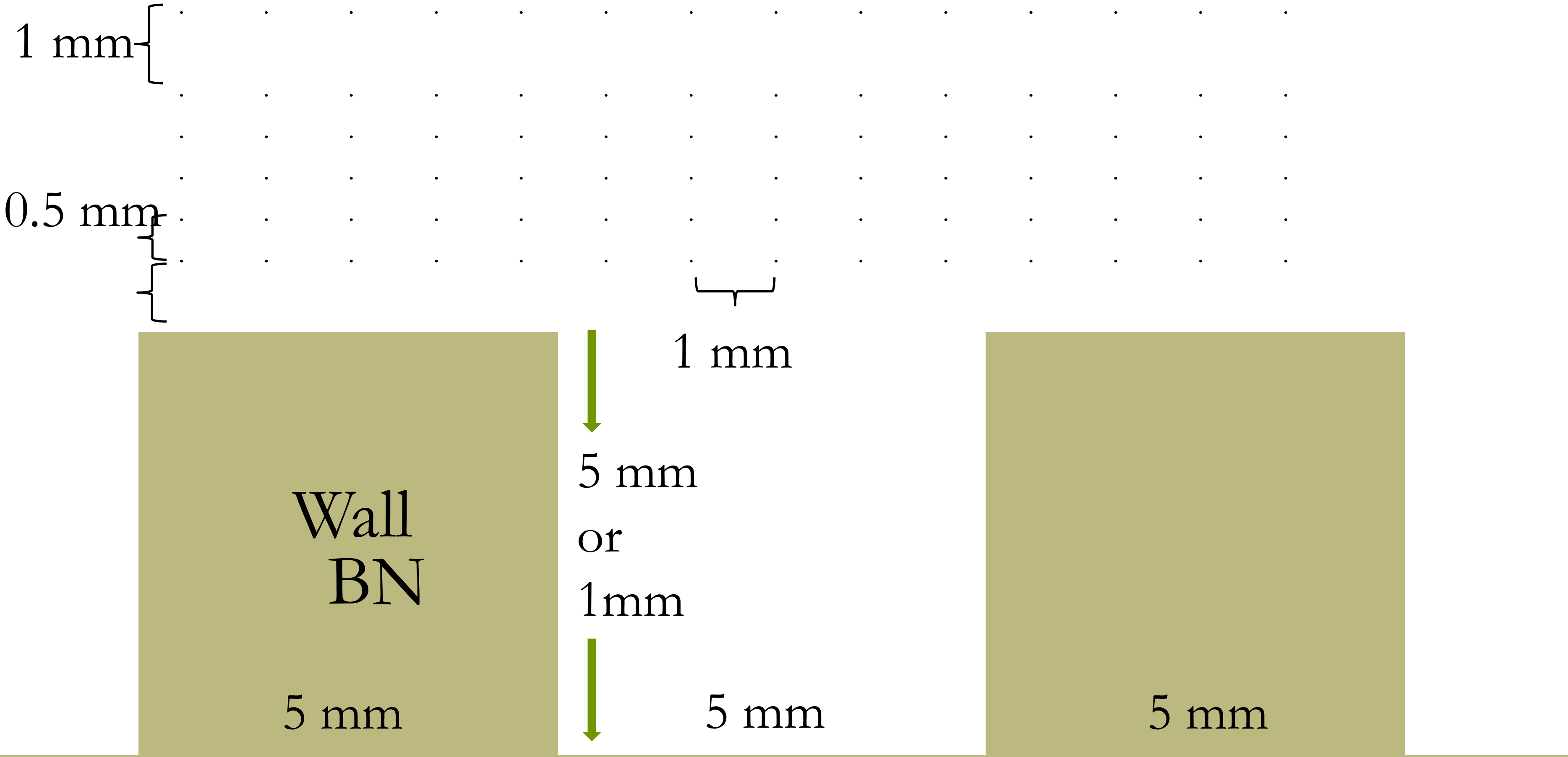
F = filaments, M = magnets, B = nominal magnetic field, PLP = planar Langmuir probe, EP = emissive probe.

The negatively-biased emissive filaments (red), the plate (green) is 50 cm apart from the filament. Gas argon, $P=10^{-4}$ Torr

Grooved BN plate



Measurement grid:



Model

Kinetic equations for electron and ion distribution functions:

$$\frac{\partial f_e}{\partial t} + \vec{v}_e \frac{\partial f_e}{\partial \vec{r}} - \frac{e\vec{E}}{m} \frac{\partial f_e}{\partial \vec{v}_e} = J_e, \quad n_e = \int f_e d\vec{v}_e,$$

$$\frac{\partial f_i}{\partial t} + \vec{v}_i \frac{\partial f_i}{\partial \vec{r}} + \frac{e\vec{E}}{M} \frac{\partial f_i}{\partial \vec{v}_i} = J_i, \quad n_i = \int f_i d\vec{v}_i,$$

Poisson equation for electrical potential and field:

$$\Delta\phi = 4\pi e(n_e - n_i), \quad E = -\frac{\partial \phi}{\partial \vec{r}}.$$

Boundary conditions:

$$\phi_{flot}(plate):$$

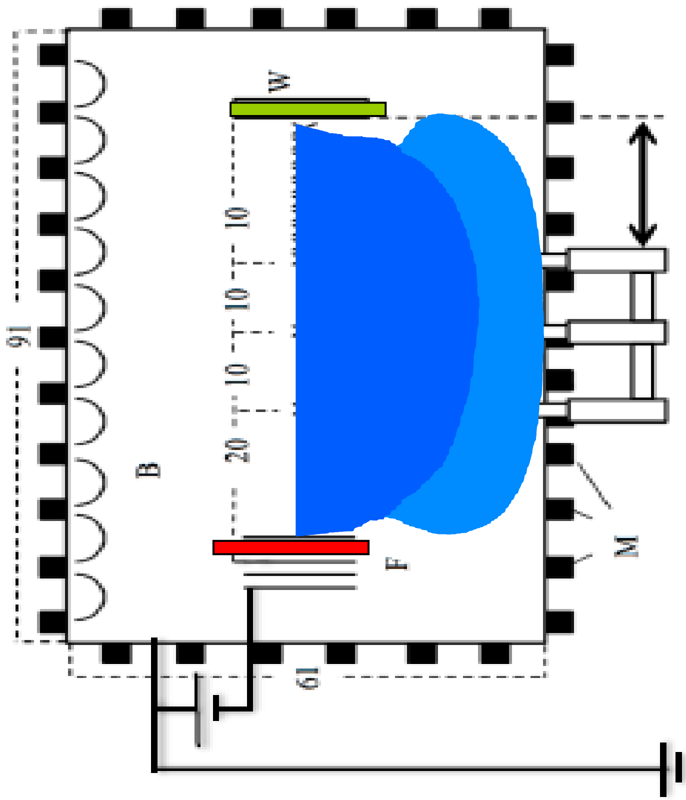
$$j_{ep} + j_{be} + j_{see\_back} = j_{see} + j_i$$

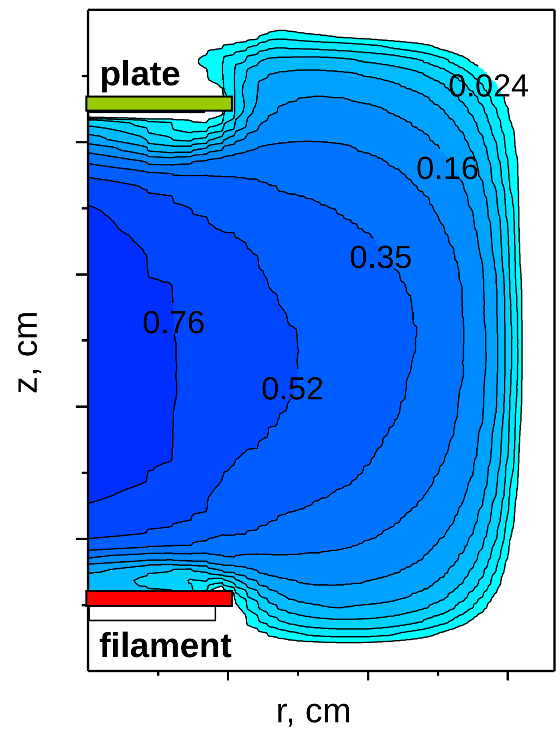
$$Ex = 0\,(walls) \quad , \quad \phi = -U\,(cathode)$$

$\gamma = (\varepsilon/E)^{\alpha}$,
$E = 30$eV,
$\alpha = 0.57$

Plasma sheath experiments

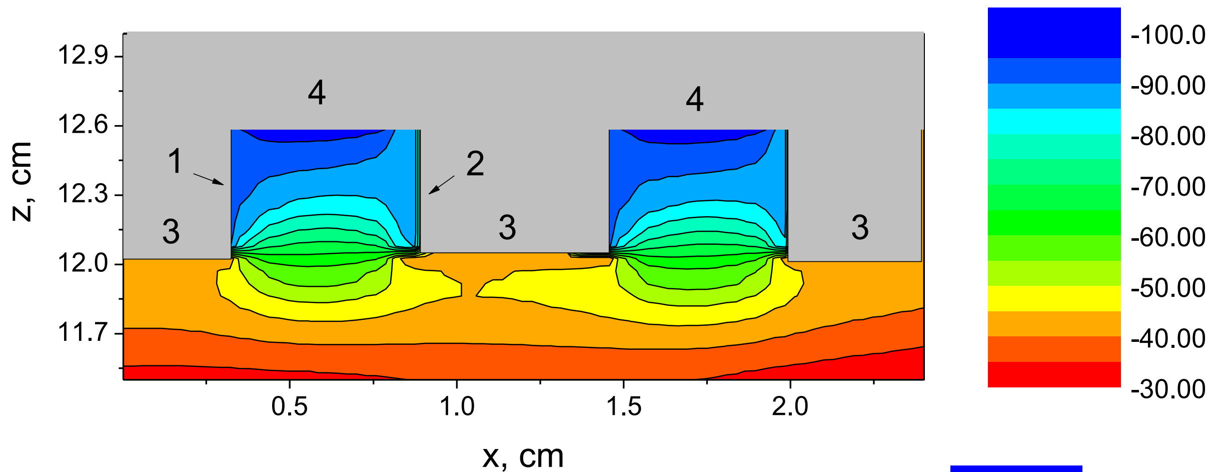
Calculation cell, electron density, $n_e/10^8\ cm^{-3}$

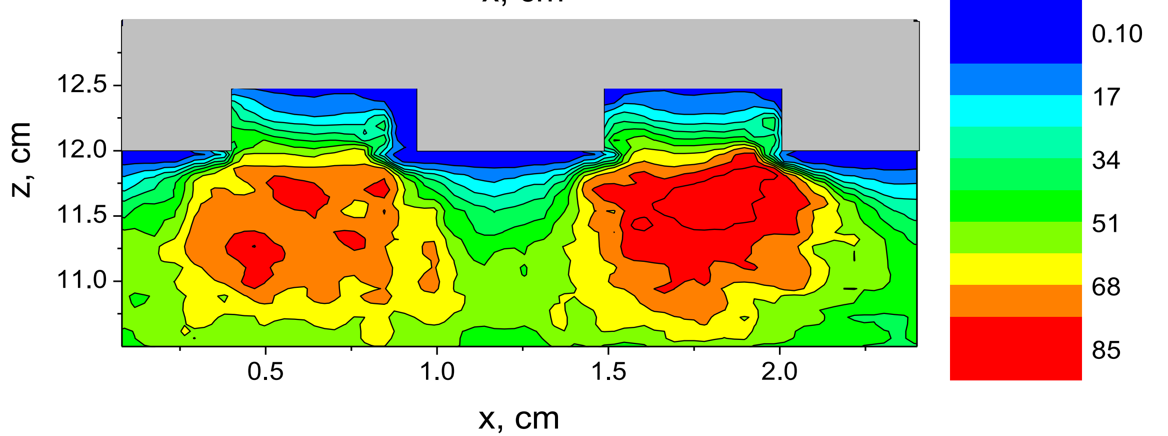




The negatively-biased emissive filament (red): U= - (70V -- 200V)
Gas argon, P=10^{-4} Torr

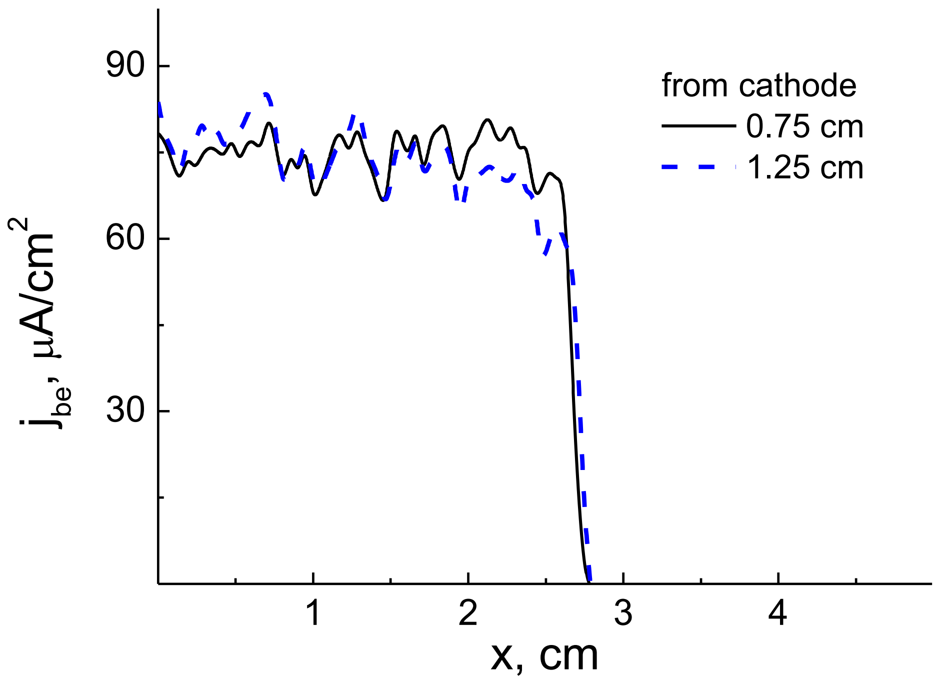
Potential and electron energy distribution over grooved surface





Potential (top) and electron energy distributions over grooved surface for the case of “developed” sheath for U=150 V.

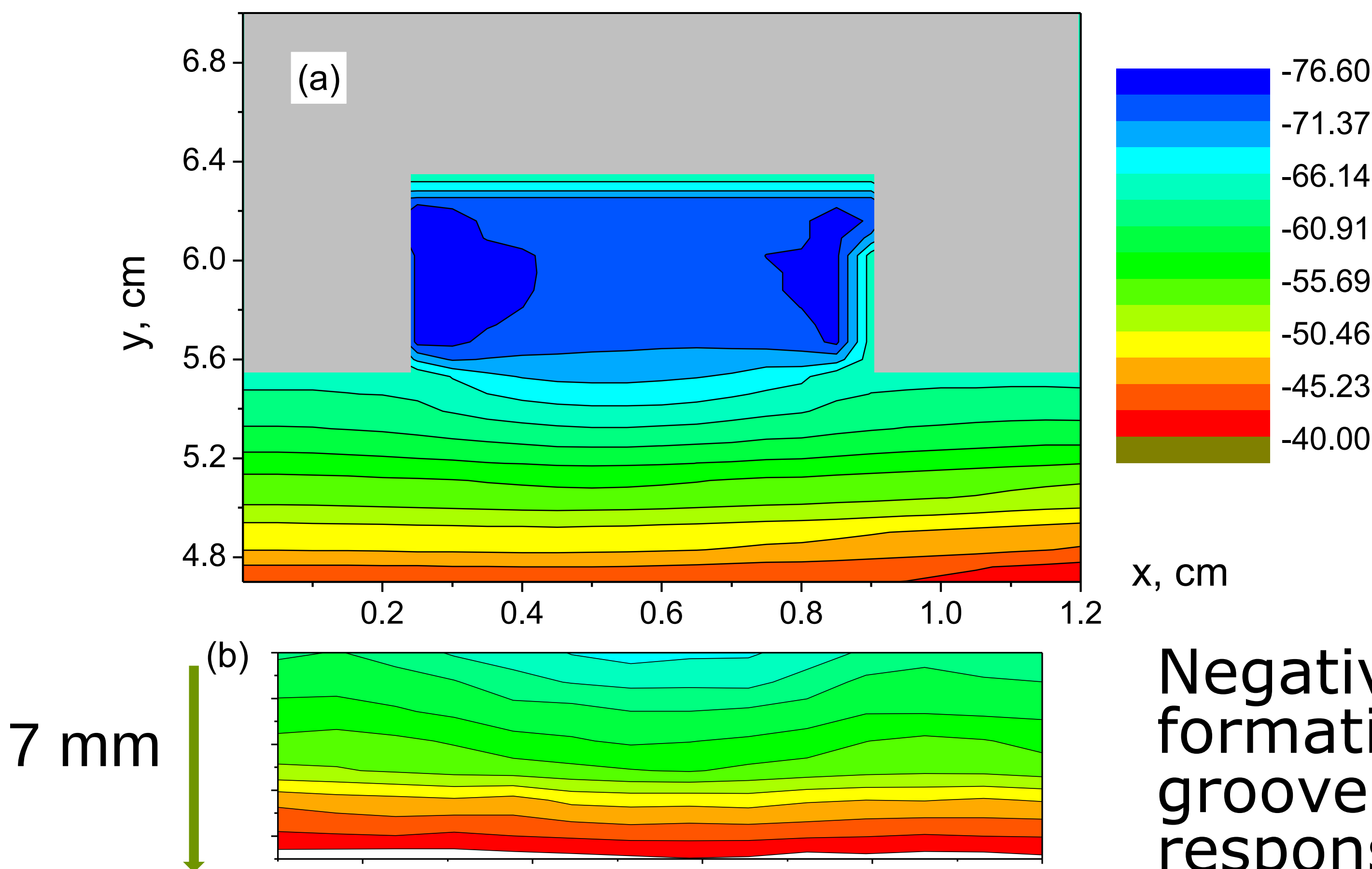
Beam electrons parameters



Beam electron current density = 75 μA/cm2 at 0.75 cm and 1.25 cm from the cathode surface for U=70 V. The beam electron density is 0.16×10^7 cm^{-3} and the plasma electron density is 2.2×10^7 cm^{-3}.

The mean electron energy in quasineutral plasma is 9 eV which is averaged over plasma electrons with 3 eV and beam electrons with 70 eV.

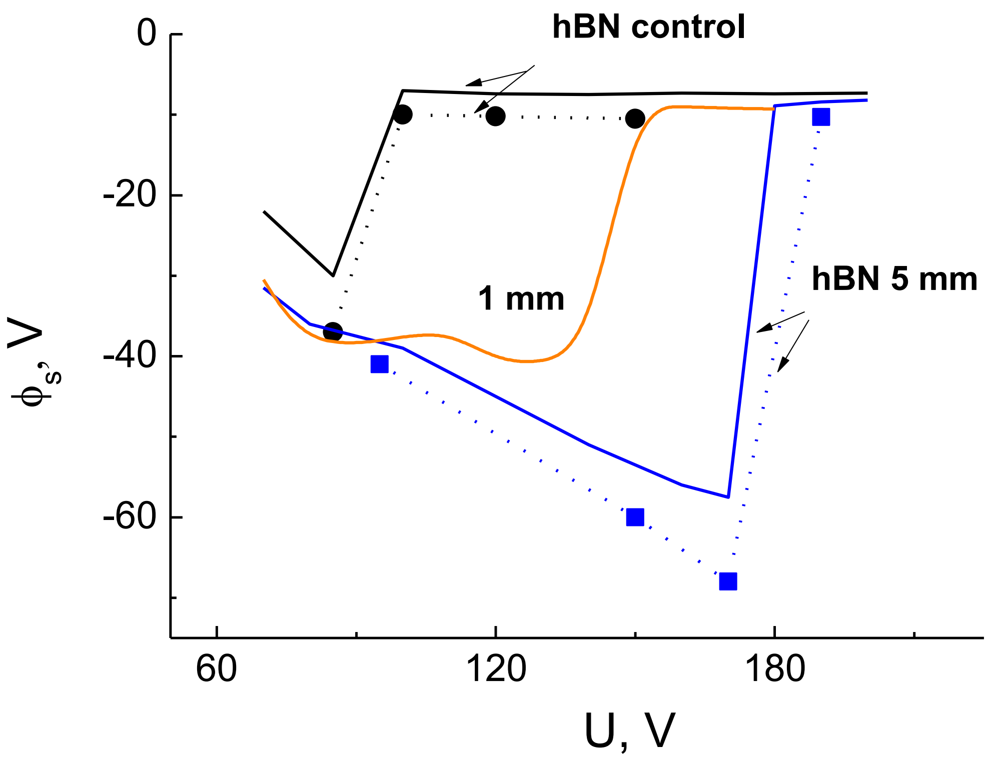
Zoom of potential distribution around grooved surface: PIC (top) and experiment (bottom)



Measurement with 0.5 mm step

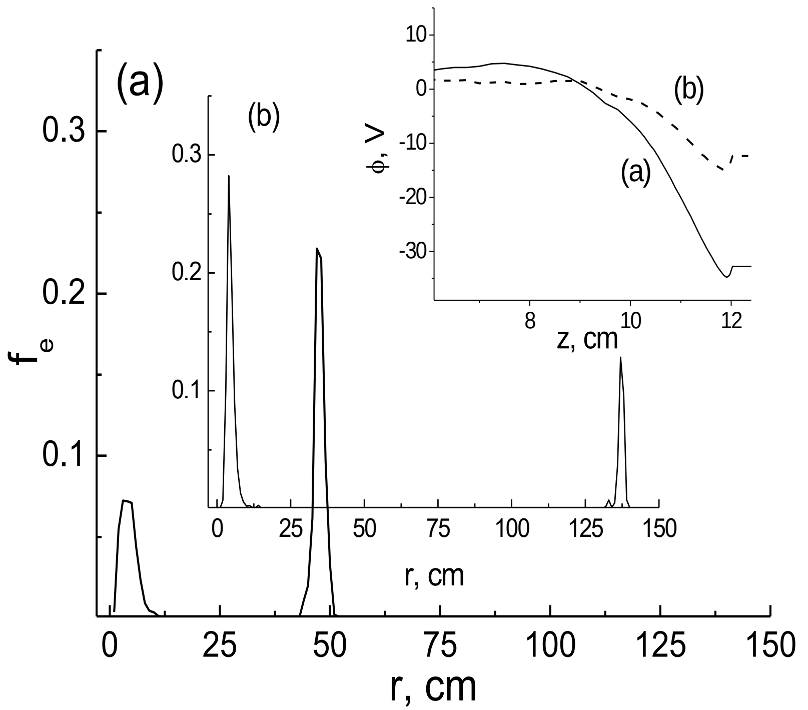
Negative charge formation near grooves is responsible for the potential distortion for U=70 V.

Transition in sheath structure (comparison of experiment and PIC results)



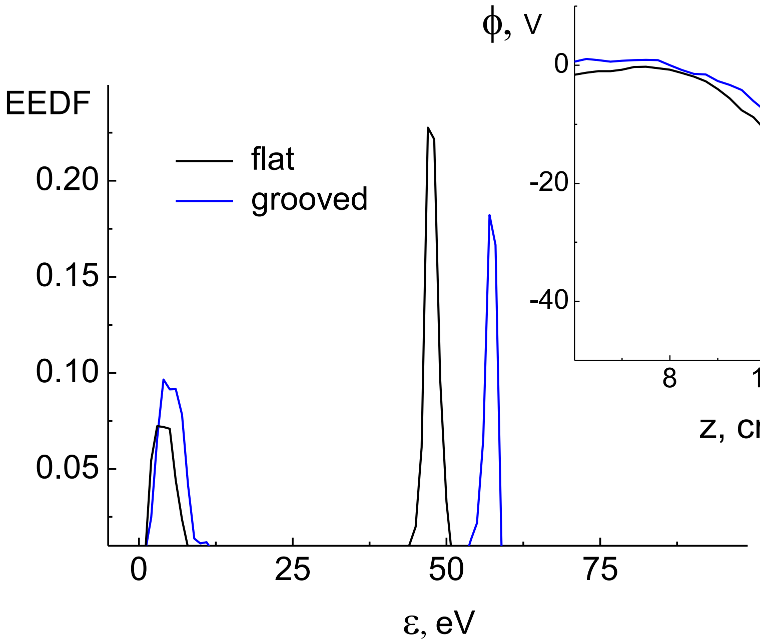
The potential drop near the plate as function of applied voltage for flat (hBN control) and grooved (with 1 mm or 5 mm depth) surfaces. Experimental data (solid lines) and calculation (symbols).

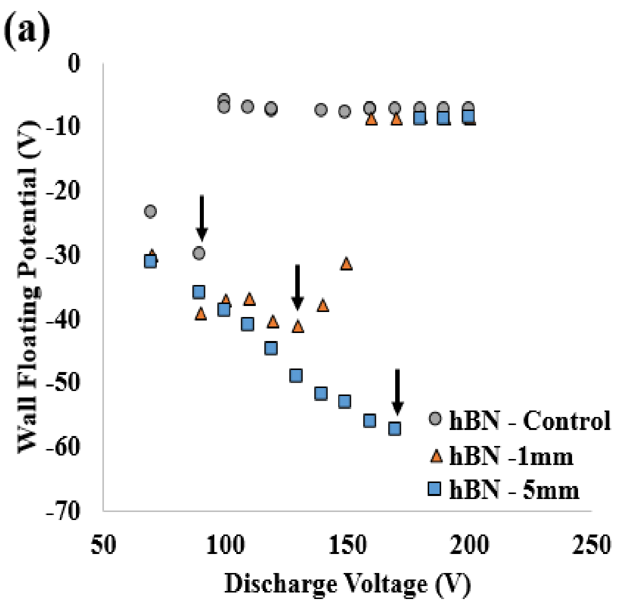
Electron energy distribution function for flat disk



Energy distribution function of electrons approaching the flat plate surface for U=90 V (a) and U=150 V (b). Insert:
the potential profiles over axis of symmetry for U=90 V and 150 V.

Calculation domain, side (a) and top view (b)

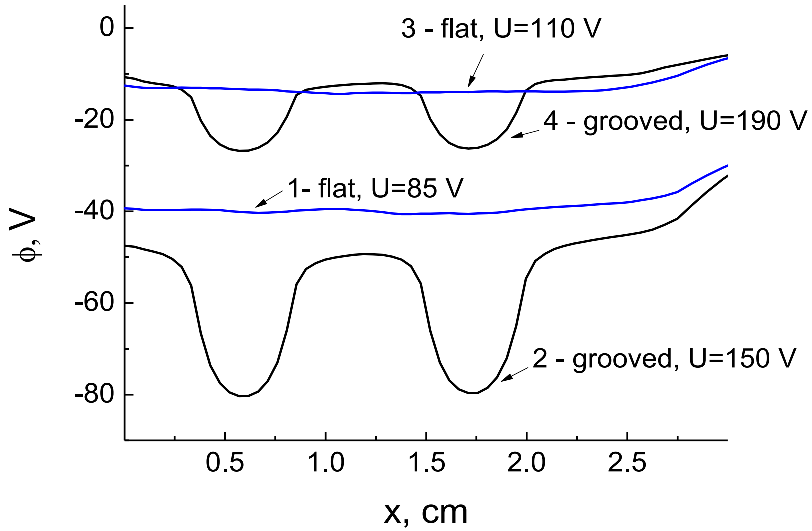


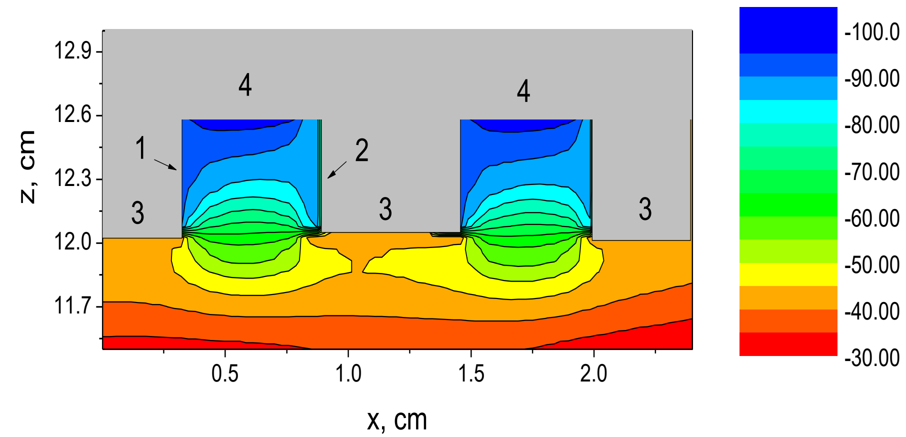


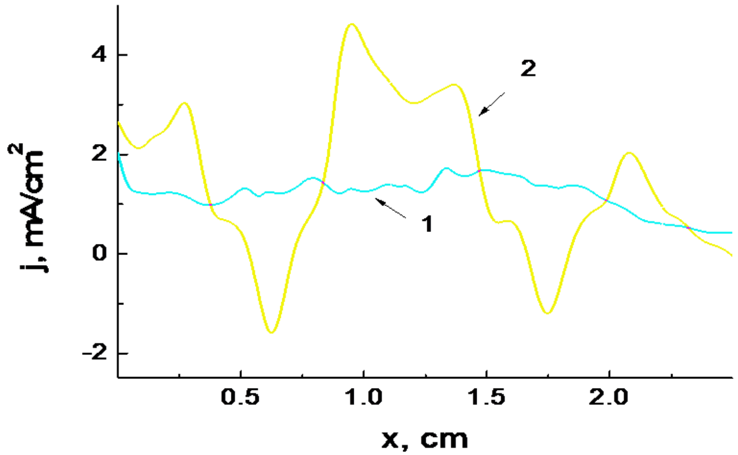
EDF for electrons arriving on the front surface of flat plate at U=85 V and grooved plate at U=95 V.

Insert: Potential profile over axis of symmetry near the flat and grooved surfaces cases

Sheath structure transition







Potential distribution (top) and electron current along the disk surface before and after transition 1 mm apart from the disk

Flat disk: U=85 V (1), U=110 V (2)

Grooved disk:

U=150V (3), U=190 V (4).

Conclusion

- A series of grooved hBN surfaces with different aspect ratio, designed to mimic the erosion channels, were exposed to an argon plasma. It was observed that for grooved surface the ‘collapse’ of sheath takes place for essentially higher voltage as compared to the planar surface.
- In PIC simulations, a mechanism responsible for an increase of sheath collapse voltage for grooved surface have been found. In the case of the grooved surface, the near-surface potential is non-monotonic. It redistributes the low energy plasma electron current from the grooves to the front surface. Though the plasma electron current to the front surface increases by factor of 2 as compared to the planar case.

The authors gratefully acknowledge FA9550-11-1-0160

PlasmaNov

2D3V PIC MCC code ***PlasmaNov*** *was developed by V. Schweigert and I. Schweigert with Birdsall, Langdon algorithm*
(Birdsall, IEEE Trans. Plasma Sci. 1991, 19, 66.
Birdsall, A. B. Langdon, Plasma Physics via Computer Simulations, IOP, Bristol 1991)

(Some papers with 2D PIC MCC ***PlasmaNov*** *simulations and algorithm details:*
I.V. Schweigert, JETP (2012), (2011);
I.V. Schweigert, V.I. Demidov, I.D. Kaganovich, Phys. Plasmas (2013);
I.V. Schweigert, D. A. Ariskin, T.V. Chernoizyumskaya, A.S. Smirnov, PSST (2011).
I.V. Schweigert, A. Alexandrov, IEEE Trans. on Plasma Science (2005).)

Calculation domain, side (a) and top view (b)