Control of Plasma Voltage Oscillations in a Short DC Discharge with an External Auxiliary Electrode

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A dc discharge (see Fig. 1) with a hot cathode (1) and bounded by the wall (2) may be subject to current and voltage plasma oscillations, which may then have deleterious effects on its operation. These oscillations can be inhibited by installing an auxiliary electrode (4), placed outside of the anode (3). By collecting a modest current through a small opening in the anode, the discharge can be stablized. This method of supressing current oscillations can be used, for example, for high current stabilizers.

Typical experimental current-voltage (I-V) characteristics of the cathode-anode gap are shown in Fig. 2 for discharges in helium. Curves 1, 2 and 3 correspond to the case without collection of the current by the auxiliary electrode. The discharge has a positive differential resistance for a pressure of 0.6 Torr (curve 1). Increasing the gas pressure to 1 Torr leads to transformation of the discharge differential resistance to being slightly negative (curve 2). Further increase of the gas pressure yields higher negative discharge differential resistance (4 Torr. curve 3). The presence of negative discharge differential resistance may lead to plasma instabilities and oscillations of the discharge voltage and current.

The collection of current to the auxiliary electrode transforms the discharge differential resistance from negative to the positive, demonstrated in Fig. 2 by curves 4, 5 and 6. Curves 4 and 5 were obtained for a gas pressure of 1 Torr and curve 6 is for 4 Torr. Each curve was obtained with fixed auxiliary electrode current. The experimental data show that an increase in the current drawn to the auxiliary electrode makes the discharge differential resistance even more positive [compare curves 4 (0.1 A) and 5 (0.4 A)). In all cases having positive differential resistance, the oscillations are suppressed and are essentially absent.

A paper on the issue has been submitted to *Rev .Sci. Instruments*. A patent application is being prepared.

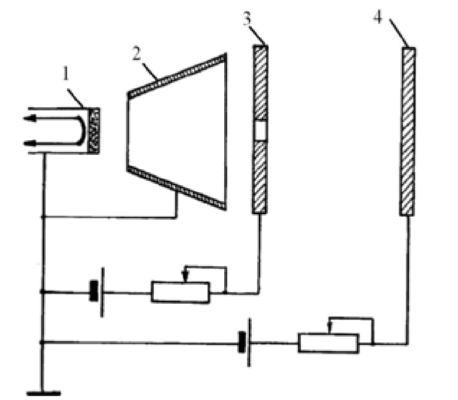


Figure 1 – Schematic of the discharge. 1) Hot cathode, 2) bounding wall, 3) anode, 4) auxiliary electrode.

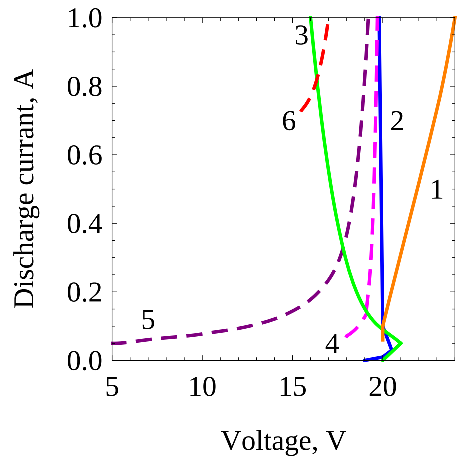
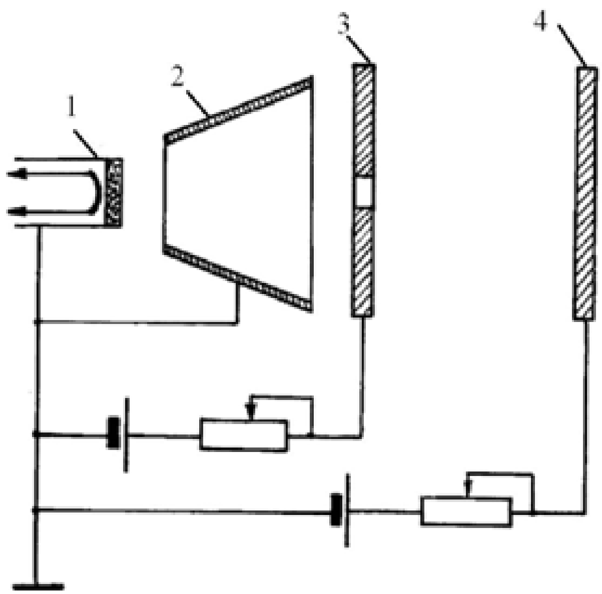


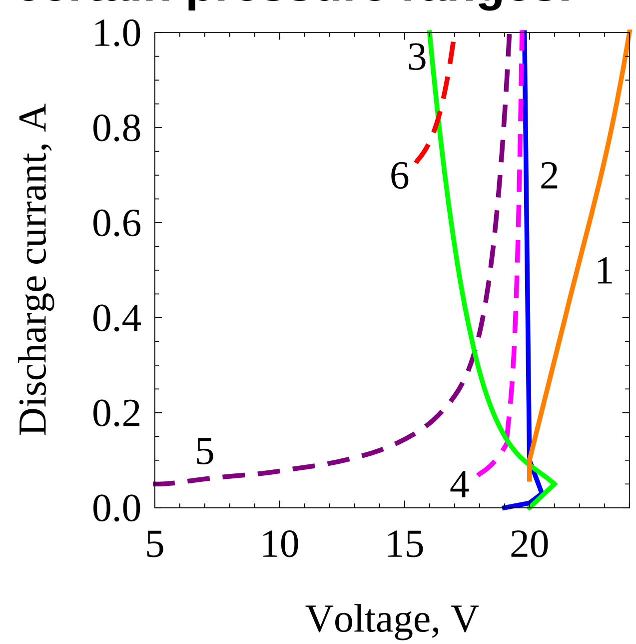
Figure 2 – IV-traces for a He discharge.

CONTROL OF VOLTAGE PLASMA OSCILLATIONS IN A DC DISCHARGE WITH AN EXTERNAL AUXILIARY ELECTRODE

- **Dc discharges with a hot cathode (diode regime) may suffer current and voltage plasma oscillations, which may be deleterious to its operation.**
- **The oscillations can be supressed by installing an auxiliary electrode, placed outside of the anode.**
- **By collecting a modest current through a small opening in the anode (triode regime), the discharge becomes stable in certain pressure ranges.**



- **Experimental Device**



- **IV-traces for diode and triode regimes**

HIGHLIGHT

Center for Predictive Control of Plasma Kinetics: Multi-Phase and Bounded Systems
Department of Energy Plasma Science Center
DOE Plasma Science Center
Control of Plasma Kinetics

Deterministic Kinetic Simulation for Non-equilibrium plasmas

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In the low temperature plasma community, two computational methods have mainly been developed and used to predict the plasma behavior. Fluid methods use macroscopic quantities, such as density, mean velocity, and temperature, enabling fast computation yet neglecting some important non-equilibrium effects. On the other hand, kinetic solvers, such as the particle-in-cell (PIC) or discrete velocity methods, are able to simulate the non-equilibrium nature of the plasma. However, statistical noise due to the use of macro-particles is mostly unavoidable in particle simulations. In particular, low plasma density regions such as near the electrodes and the tail of velocity distribution functions (VDFs) (that is, the high energy electrons), suffer from inaccurate simulation due to inherent statistical noise.

The key feature of this study is to develop a deterministic kinetic (DK) simulation method that solves the kinetic Boltzmann equation for non-equilibrium plasmas. VDFs are obtained directly by discretizing the phase space, including both physical and velocity spaces. Here, the DK method is applied to the discharge plasma of a SPT-100 Hall thruster, which is in a non-equilibrium state due to the complex mechanisms such as plasma oscillations and collisions. The results are compared to a PIC simulation. In order to compare the features of the kinetic methods, both kinetic models are used for heavy species and an identical fluid model is used for electrons. The results obtained from the hybrid-DK method are in good agreement with the hybrid-PIC results and experiments in terms of the time averaged plasma properties [1]. However, differences are seen in the time resolved results. The instantaneous VDFs of ions at the channel exit are shown in Fig. 1. The DK simulation provides improved resolution of VDFs and thus temporally/spatially well resolved plasma properties in comparison to the PIC results where statistical noise is present. In order to reduce the computational cost, Graphics Processing Unit (GPU) computing is considered to be suitable for DK solvers [2]. Currently, we are working on GPU acceleration and applying the DK simulation to other cases.

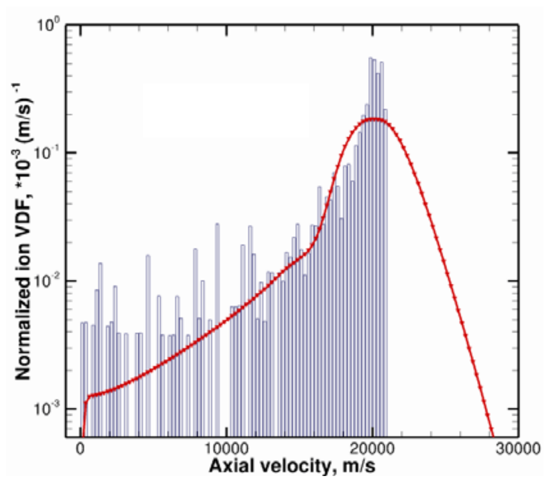


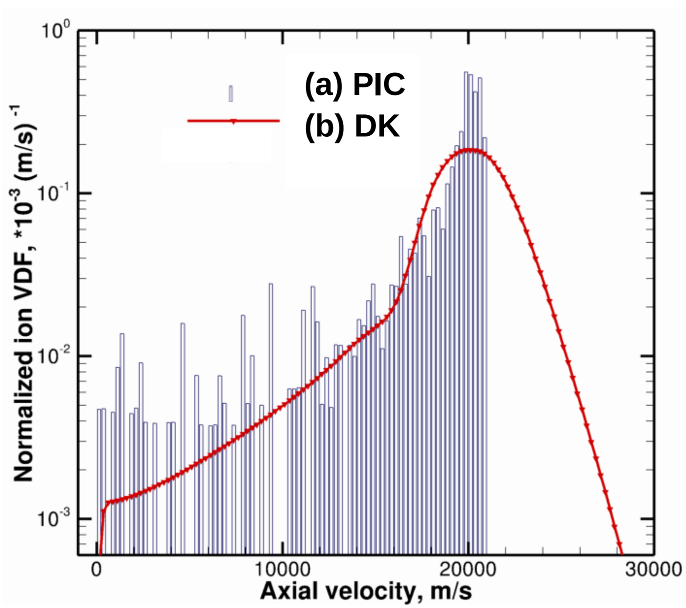
Figure 1 - Instantaneous velocity distribution functions of ions at the exit channel of a SPT-100 Hall thruste. (Solid line: hybrid-DK, Dashed line: hybrid-PIC.)

References

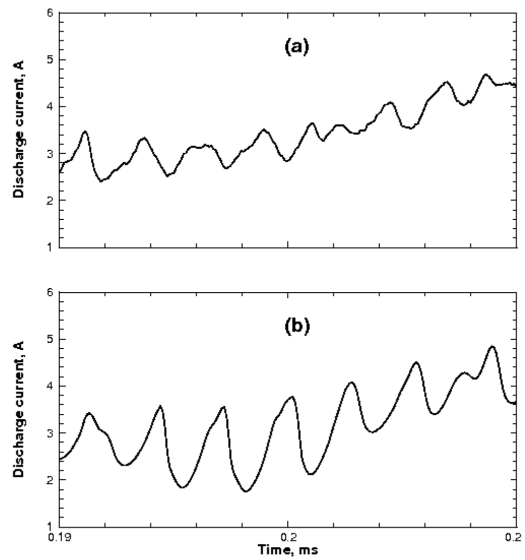
[1] K. Hara, I. D. Boyd, and V. I. Kolobov, AIAA Paper 2012-4313, (2012).
[2] V. I. Kolobov and R. R. Arslanbekov, J. Comput. Phys. **231**, 1 (2012).

DETERMINISTIC KINETIC SIMULATION FOR NON-EQUILIBRIUM PLASMAS

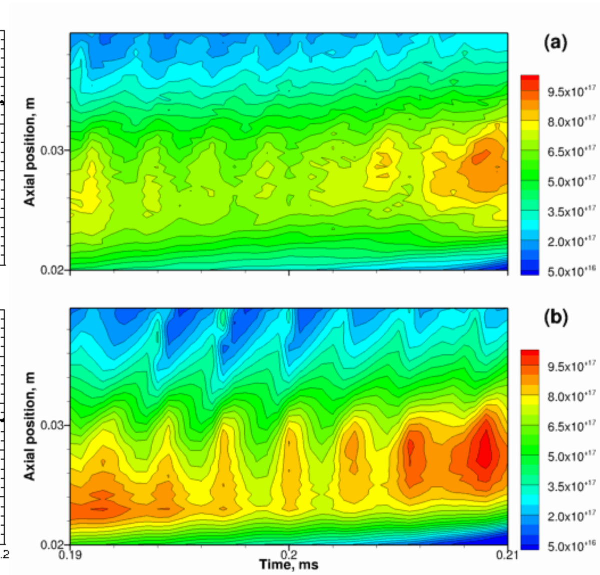
- In order to understand and predict the behavior of non-equilibrium plasmas, velocity distribution functions (VDFs) must be obtained accurately.
- For the discharge plasma of a Hall thruster, using a deterministic kinetic (DK) simulation method that solves the Boltzmann equation directly, improved resolution of VDFs is achieved in comparison to a particle-in-cell (PIC) method.
- Temporally and spatially well resolved plasma properties are obtained



- Ion VDF at the channel exit of a Hall thruster. (a) PIC, (b) DK



- Discharge current vs. time



- Ion number density. x-axis: time, y-axis: position

PLSC_0912 **HIGHLIGHT** University of Michigan

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