Electron temperature of thruster plume plasma in far field

Boris Vayner

Ohio Aerospace Institute, Cleveland, Ohio 44142, USA

Voluminous arrays of data were obtained experimentally for various types of plasma thrusters operated in diverse chambers, and common conclusions were accepted: electron temperature decreased with distance from thruster orifice and increased with the background pressure decreasing. Plume plasma electron temperature is a very important parameter for evaluating the interactions between spacecraft elements and thruster plume. All measurements performed in vacuum chambers indicated rather low electron temperatures (0.5-2 eV) in the far field while computer simulations and measurements in space (one only) pointed to significantly higher temperatures (3-6 eV). The physical mechanisms of electron cooling in far field were not understood because of seemly collisionless electron gas in a vessel. It is shown in current paper that electron cooling in plasma chamber is caused by creation of potential barrier near walls, and this barrier originates from self-organization of electrically neutral plasma.

1.Introduction

In order to perform tests in vacuum vessels one needs to know the parameters of the plume plasma in very far field. There are two complimentary approaches to the search for a solution to this problem: 1) performing extensive computer simulations; 2) measuring plasma parameters in ground chambers. These two approaches are mutually intertwined, but the results are frequently contradictive. Generally speaking, plume plasma parameters in a chamber and space are different: backpressure of neutral gas and vessel's walls influence on plasma density, plasma potential, and electron temperature. The quantitative characteristics of these differences for any thruster depend on chamber dimensions and pumping speed [1]. The comprehensive study of all these factors was performed earlier. Background pressure (Xenon) varied from 3.5 µTorr to 73 µTorr. The electron temperature variations at the distance of 1 m from thruster exit plane (at the angle of 50 deg from axis) were determined within the range of 1-2 eV for floating thruster and 0.9-1.3 eV for thruster grounded. The electron temperature increased with pressure decreasing, and measurements error was estimated at 20%. In order to establish adequate test conditions the influence of a test arrangement on plume plasma parameters was analyzed and some criteria for appropriate ground test conditions were presented.

2. Ground experiments

The effect of backpressure was studied for P5 Hall thruster in a quite large chamber with a diameter of 6 m and length of 9 m. Two sets of measurements were performed at xenon background pressures of 3.6 µTorr and 11 µTorr. Probes were positioned at the distance of 1 m from exit plane, which was equal to seven thruster diameters approximately (D_0=148 mm). Certainly, ion current density was decreased about two times with increased pressure, and electron number density demonstrated dependence on pressure with factors of 2-4. Electron temperature varied within the range of T_e=1.2-1.6 eV, and no correlations were established between electron temperature and neutral gas pressure. Plasma properties of Electron Cyclotron Resonance (ECR) thruster in the near field (2 cm from exit plane) were investigated. Electron temperature decreased with increasing flow rate: T_e=2.5-3 eV at $\dot{m} = 20\,sccm$, and T_e=1.3-2.3 eV at $\dot{m} = 36\,sccm.$ These results were obtained in fairly large chamber (D=2.2 m, L=7.9 m), and they confirmed that low electron temperatures were caused by processes inside the thruster but not the influence of background gas pressure.

Plasma plume properties of the cluster of four BHT-200 Hall thrusters were measured at the distances comparable with assembly dimensions. Somewhat higher electron temperatures were recorded in far field for 1.5 kW Hall thrusters (PPS-100ML and PPI).

3. References

[1] B. Vayner. XXXIth ICPIG, July 14-19, 2013, Granada, Spain