Analysis of Ion and Neutral Behavior inside a Miniature Ion Thruster and Neutralizer with Respect to Inlet Configuration Utilizing Numerical Simulation

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論 文 名　:（数値計算を用いたインレット構成に関する小型イオンスラスタおよび中和器内部におけるイオンおよび中性粒子の挙動解析)

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論 文 内 容 の 要 旨

Thesis Summary

Our research focuses on the simulation of plasma particles within a miniature ion thruster and neutralizer. It is well known that the electron density distribution and microwave plasma coupling plays a major role in determining the performance of a miniature thruster. However, the impact of neutral density distribution and neural recycle rate within the thruster is not well studied. Since the neutral density can easily be influenced and altered with simple changes made to the gas inlet configuration, we developed the hypothesis that altering the gas inlet configuration within a neutralizer and ion thruster would lead to significant changes to the natural density distribution and consequently possible changes to the ionization pattern, ion density and neutral recycle rate. With that in mind we aimed to develop an all-inclusive 3D FDTD-PIC simulation of plasma inside the discharge chamber where all particles (ions, electrons and neutrals) are treated as active particles. At first we developed a neutrals only 3D PIC code to evaluate the impact of neutrals density distribution inside a neutralizer to test the assumption that inlet configuration can alter the neutral density significantly. This simulation resulted in a clear observation of the changes within the discharge chamber in neutral density distribution with regards to the inlet changes.

Next we developed a simplified ion-neutral code where the effects of electromagnetic field was ignored, to analyze the neutral recycle impact within a neutralizer and test the assumption that the inlet configuration has the potential to alter the neutral recycle rate pattern within the discharge chamber as a result of gas inlet configuration. Although this simulation had limited scope in terms of accuracy (the electromagnetic field being ignored) it showed the potential to alter the ion loss pattern by adjusting the gas

inlet configuration. With this result we worked on developing a full 3D FDTD-PIC simulation of a miniature ion thruster with a Poisson solver to fully analyze the impact of gas inlet configuration of neutral and ion density and neutral recycle rate within the discharge chamber. We incorporated a very fine mesh size of 0.1 mm and decided to not include an artificial sheath potential as a first step in developing a more realistic simulations. Although our current code cannot simulate the plasma sheath as accurately as we hope due to the large mesh size, due to our current hardware limitations we hope this code would be a stepping stone in the near future were advancements in hardware technology will allow for a simulation with a much smaller mesh size to enable sheath simulation. With that limitation in mind we set to analyze the ion-neutral behavior for two candidate antennas (L shaped and Disk shaped) as well as four candidate inlet configurators.

The simulation results indicated a clear shift in ion and neutral densities towards the gas inlet especially in the single horizontal inlet configurations for both antenna shapes. However the impact for the L shaped antenna was more prominent. On the other hand, the four horizontal inlet configuration led to a significantly higher rate of ionization in the vicinity of the disk shaped antenna which was then counteracted by neutral recycle impact. Moreover, the simulation of the neutral recycle rate showed a clear pattern towards the position of the gas inlet where the single inlets experienced and increased rate of ion loss in the walls closer to the inlets. Despite these changes, the average ion and neutral densities in the discharge chamber remained largely unchanged leading to the conclusion that the changes in the ionization pattern and ion density are mainly local and may not translate into larger meaningful outcomes for the engine performance. Despite this, we recommend further research into the possibility of the single horizontal inlet configuration for the L shaped antenna and the four horizontal inlets configuration for the disk shaped antenna as an alternative. Further experiments are recommended to assess the impact of these recommendations for the proposed engines.