

## 3D DSMC Simulation of Neutral Particles in Miniature Ion Thruster

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**Abstract:** Antenna configuration in an ion thruster determines the electron density distribution throughout the engine which leads to unique ionization patterns. In order to maximize the ionization, high neutral density in these ionization areas is essential. Moreover the neutral density distribution of ion thrusters is solely dependent on the configuration of the gas inlet. We have developed an original 3D DSMC (Direct Simulation Monte Carlo) simulation of neutral particles in a miniature ion thrusters for one of our developed thrusters. The variation in neutral density distribution and velocity distribution is analyzed to ensure the accuracy of the simulation.

**Keywords:** Electric Propulsion, Particle Simulation, Miniature Ion Thruster

### 1. INTRODUCTION

Our research involves the development of realistic numerical simulation for Miniature microwave Ion Thrusters. An ion engine produces high thrust efficiency, exceeding 70%, with specific impulse of 3,000-8,000 s. Therefore, miniature ion engines are candidates for use as miniature propulsion system for small satellites [1]. Since the ion engine is so small that we cannot insert a measurement equipment without perturbations. Numerical simulations are effective tool to understand the phenomena occurring in a miniature microwave ion thruster [2]. We utilize the DSMC method for this simulation as The DSMC method [3] works by moving the simulation particles through a finite time step through a discretized computational domain. After each push, particles are paired up with other particles located in the same computational mesh and collision probability is computed for these pairs. Those pairs that are colliding then have their velocities modified in a way that conserves energy and momentum. By analyzing the inlet position and configuration we can determine the neutral density distribution throughout the engine and examine its effectiveness. For a comparative study we chose one of the miniature thrusters Developed in Yamamoto research group in Kyushu University (depicted in Figure 1) as the sample engine and adjusted the simulation to it. The antenna depicted in the Figure is a star shaped antenna, since the shape of the antenna does not affect the neutral density distribution, we picked an L shaped antenna for our simulations with a bottom gas inlet located right below the L shape of the antenna in the shape of a 2 mm square with a depth of 10 mm. The simulation properties are indicated in table 1. As it can be seen in table 1, in order to achieve a more accurate and realistic simulation we have considered a very low super particle number which will greatly influence the calculation time. To deal with that we adapted a hybrid OpenMP-MPI parallelization method for all the simulation cases. The simulation runs for a real time of 40 ms which is enough for the system to reach a steady state in which the flux of incoming particles form the inlet is similar to the flux of particles leaving the engine. This simulation considers neutral Xenon particles at room temperature (298 K) fed at the bottom of the inlet at the specified mass flow rate. The simulation also includes elastic collisions between particles and atom wall interactions which assumes a

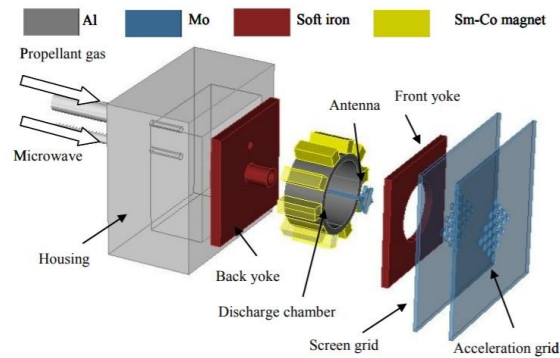


Fig. 1. An ion thruster developed in Yamamoto lab in Kyushu University adopted from “Numerical Analysis of Microwave Discharge Type Compact Ion Engine” Masters Thesis. Kyushu University Fukuoka, Japan, (2010).

closed boundary except for the end of the engines orifice where the particles leave the engine [5].

Table 1. Simulation Properties

Grid Size	$0.5 \times 10^{-3}$ m
Time Step	$5 \times 10^{-8}$ s
Super Particle Number	$0.5 \times 10^9$
Mass Flow rate	$0.49 \times 10^{-1}$ mg/s

### 2. RESULTS

In order to validate the results of the simulations, we have calculated the average density of neutrals in the discharge chamber and compared it with the theoretical density expected using the vacuum conductance theory as follows [6]. Therefore the calculated average density for the neutral particles in our engine is  $5.32 \times 10^{20} \text{ m}^{-3}$ . The average particle density of the simulation was within the acceptable range of the theoretical value and therefore the validity of the simulation is confirmed. Furthermore the velocity distribution of particles within the engine should be validated and it should follow a maxwellian distribution with the most probable velocity corresponding to [7]:

$$C_{mp} = \sqrt{2R_m T} = 194.25 \text{ m/s}$$

Figures 2 and 3 indicate the velocity distribution of particles within the engine where the most probable velocity is validated. Figure 2 indicates the velocity distribution for select random particles within the engine. It is obvious that the simulation follows a maxwellian distribution with the peak nearing the 200 m/s which is close to the theoretical value. In order to further evaluate the accuracy of this velocity distribution we separated the particles in figure 2 into their respective positions within the engine and as it is shown in figure 3, each section of the engine still follows the maxwellian distribution with the most probable velocity peaking near 200 m/s. The density distribution results are shown in Figures 4 and 5. Figure 4 shows the vertical cross section of the engine drawn from the middle of the engines X axis and Figure 5 indicates the horizontal cross section at the antenna's top L shape. As mentioned earlier, the desired density around the antenna relies on the antenna shape. For an L shaped antenna we would hope for a higher density of neutrals around the L part of the antenna while for other symmetric antenna shapes such as star shape or disk shape, we prefer a more uniform distribution. Figure 5 indicates the density distribution for the inlet located at the bottom of the antenna. It can be seen that there is a higher concentration of neutrals around the L part of the antenna where the opposite side lacks this higher density. This inlet configuration is suitable for the L shaped antenna however it would not be the best option for other symmetric antenna shapes.

### 3. CONCLUSION

A 3D DSMC simulation of neutral particles with a conventional bottom inlet considering velocity distribution was conducted and the results were analyzed. We considered an L shaped antenna as a sample for our simulation study. As far as the L shaped antenna is concerned, we concluded the inlet at bottom of the antenna was a suitable options since the offer a higher concentration of neutrals facing the L part of the antenna. Moreover the velocity distribution of particles were validated in this simulation further proving the accuracy of this simulation method.

The Barbieri/Van Hove symmetrized automated tensor LEED package was used to calculate the theoretical I(E) curves of the structure models to determine the atomic positions. [31] The calculations for the atomic scattering was performed by considering 13 phase shifts ( $l_{max}=12$ ) whereas the imaginary part of the inner potential ( $V_{oi}$ ) was fixed to  $-5.0$  eV and the real part was determined through theoretical-experimental matching and attributed by minimizing Pendry's reliability factor ( $R_p$ ). [32] The error bars on the structural parameters were calculated from the variance of  $R_p$ ,  $\Delta R = R_{min}(8|V_{oi}|/\Delta E)^{1/2}$ , where  $R_{min}$  is the minimum  $R_p$  value and  $\Delta E$  is the total energy range of the experimental I(E) curves. [32]

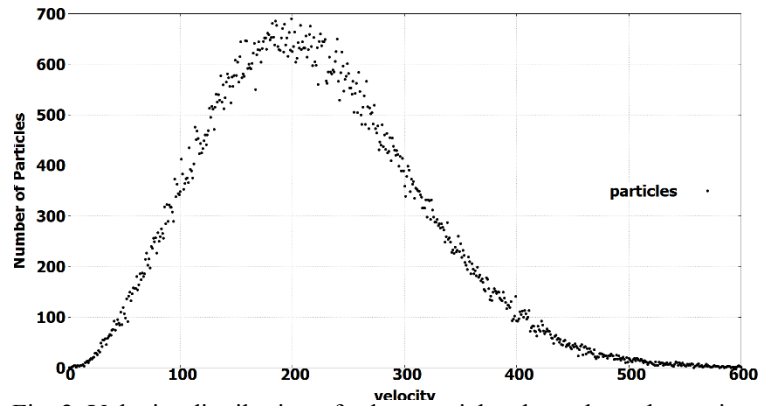


Fig. 2. Velocity distribution of select particles throughout the engine

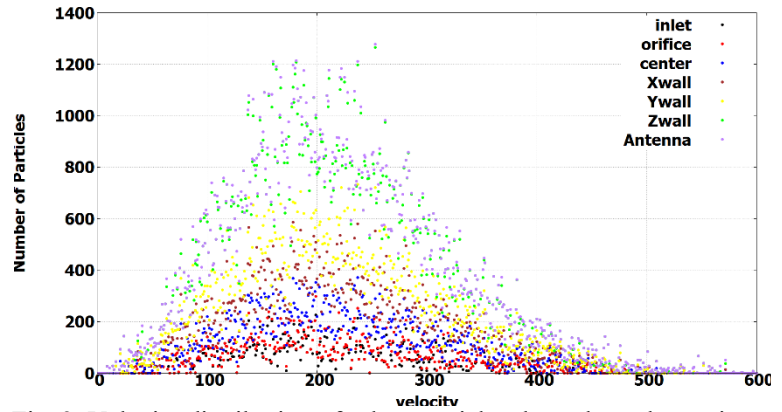


Fig. 3. Velocity distribution of select particles throughout the engine with respect to position

### 4. REFERENCES

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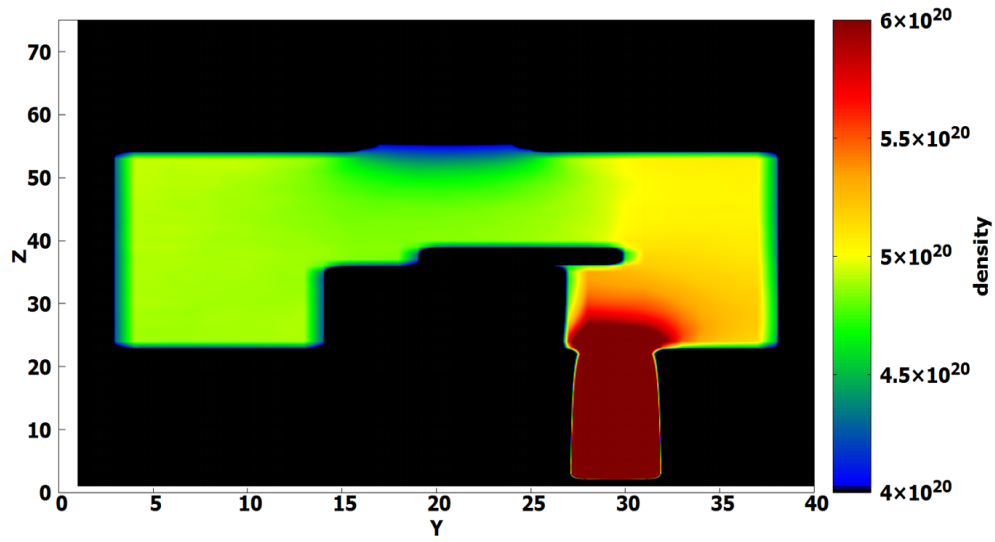


Fig. 4. Velocity distribution of select particles throughout the engine

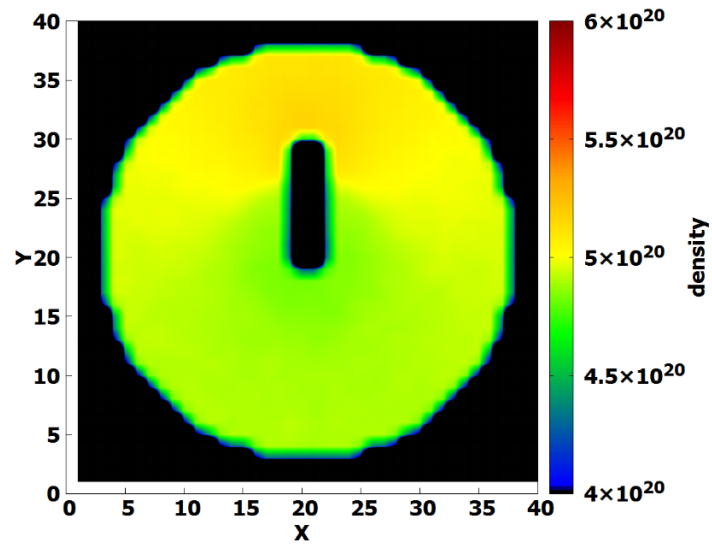


Fig. 5. Horizontal cross section density distribution of neutrals for the bottom inlet