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大気圧ミリ波放電の伸展モデルとその数値解析
Modeling of Millimeter-Wave Discharge Extension under Atmospheric Pressure and Its Numerical Analysis

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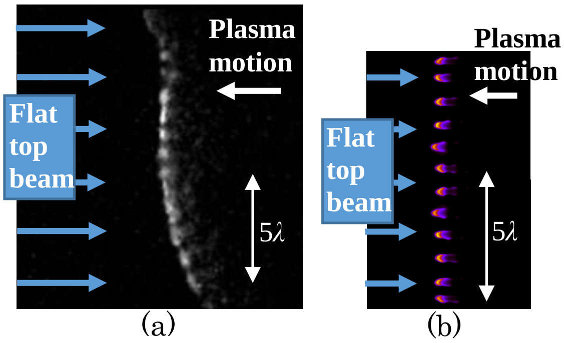
1. Introduction

Nowadays development in high power millimeter-wave oscillator Gyrotron enables observations of several new phenomena caused by high power millimeter-wave. One of these are propagation of millimeter-wave discharge. In this phenomenon a seed plasmoid irradiated with subcritical power-density millimeter-wave extend toward the beam source. This is attracting interest because propagation velocity is one order faster than laser discharge, however an applicable physical model describing the relation between the discharge phenomenon and wave frequency/ power density is yet to be discovered.

In previous experiments, the plasma which is divided into small pieces during its extension is observed (**Fig. 1** (a)). The pitch of each plasma pieces is around 0.8λ while λ is the wavelength of incident beam. This suggests that some beam energy concentration occur at the plasma front. The purpose of this study is to reproduce this plasmoids by computation and to reveal the cause and effect of this phenomenon.



(a) (b)

Fig. 1 (a) A flaming camera image of millimeter-wave discharge. 170 GHz, ca. 1 GW/m^2, exposure time 100 ns, discharge propagation velocity ca. 1 km/s. (b) Computed plasma density contours. Maximum density ca. 2×10^{21} /m^3, 170 GHz, discharge propagation velocity ca. 4 km/s.

2. Computational Method

In spite of many researches which compute propagation of millimeter wave discharge1), 2), there is no research which reproduce the situation shown in **Fig. 1** (a). This is because the computational method used is applicable to the case where the beam intensity is very close to that of the discharge threshold and moreover the experimental value of beam intensity is much lower than the threshold. In this study, the method used is similar to well-known ones, but parameters for lower intensity case are refitted. Electro-magnetic field are calculated with S_{24} FDTD method which is 2nd order accurate in time and 4th order accurate in space3). Plasma is calculated with fluid model equation.

The calculation is conducted on a plane containing electric field direction and beam direction whose size is $7\lambda \times 7.5\lambda$. The computational domain is reproduced using one of the long side boundaries as the center line. One of the short side boundaries generates uniform electro-magnetic waves and the other short side together with the adjacent long side act as the absorbing boundaries. Initial conditions are set with seed plasmoids on the opposite area of the beam generating boundary. Many computations are conducted changing seed-plasma distribution, propagation velocity and frequency.

3. Results and Conclusion

One of the results is shown in **Fig. 1** (b). Regardless of seed plasma distribution, extension velocity and beam frequency, extending plasma are separated into pieces and finally lined up with the same pitch size is of approximately 0.8λ. This result showed good agreement with the experimental results. **Fig. 2** shows the relationship between the pitch size and the propagation velocity obtained from the computation at 170 GHz. This shows that the pitch size is independent of propagation velocity.

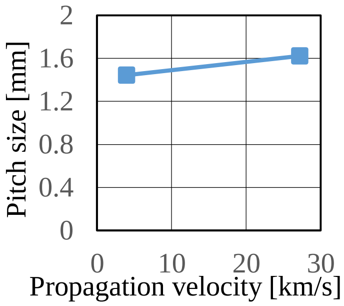


Fig. 2 Plasmoids pitch size vs. Propagation velocity. λ=1.76 mm. One plot is ca. 4 km/s and the other is ca. 27 km/s.

References

1) J. P. Boeuf et al., *Phys. Rev. Lett.*, **104**(2010), 015002
2) Q. Zhou et al., *Appl. Phys. Lett.*, **98**(2011), 161504
3) M. F. Hadi et al., *IEEE Trans. Antennas Propagat.* **45**(1997), 254-264