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Propagating Velocity Control of Atmospheric Millimeter Wave Plasma and Its Application to Microwave Rocket
大気圧ミリ波プラズマの伝播速度制御とそのマイクロ波ロケットへの応用

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The propagating velocity of millimeter-wave supported detonation is one of the key parameters for thrust performance of Microwave Rocket and it is faster than that of laser supported detonation (LSD), resulting in lower heating rate in the ionized region and lower pressure behind the detonation wave than LSD. In the experiments, thrust performance was enhanced by reducing the propagating velocity of ionization front, which is achieved by converting the millimeter-wave beam from the Gaussian profile into a flat-top profile.

1. Introduction and Propagating Structure inside Microwave Rocket

A Microwave Rocket is a future low-cost launcher to the space, as shown in Fig. 1. Propulsive energy is repetitively supplied by pulsed millimeter wave beams irradiated from the ground and the atmospheric air is used as a propellant, so that it can be propelled without any energy sources or propellants on-board [1]. Microwave Rocket consists of a reflector to ignite and a cylindrical tube to keep high pressure inside. Figure 2 shows the thrust generation model. The closed end of the cylindrical tube has a beam-focusing reflector called “thrust wall” and the other end serves as an entrance for the millimeter wave beam, from which also air is exhausted and refilled after the end of a thrust generation cycle [2].

A propagating structure inside a Microwave Rocket is millimeter-wave supported detonation, consisting of shock wave and plasma as millimeter wave absorption layer, as shown in Fig. 3. The propagating velocity of millimeter-wave supported detonation is one of the key parameters for thrust performance of Microwave Rocket and in previous study it was faster than that of laser supported detonation (LSD) at the same power density [3,4]. This faster velocity can lead lower heating rate in the ionized region and lower pressure behind the detonation wave than LSD.

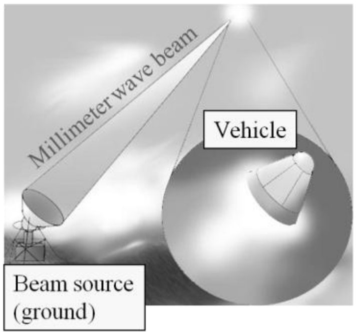

Fig.1. Schematic figure of Microwave Rocket

Therefore the objective of this study is to reduce the detonation wave velocity and to enhance the thrust performance of Microwave Rocket.

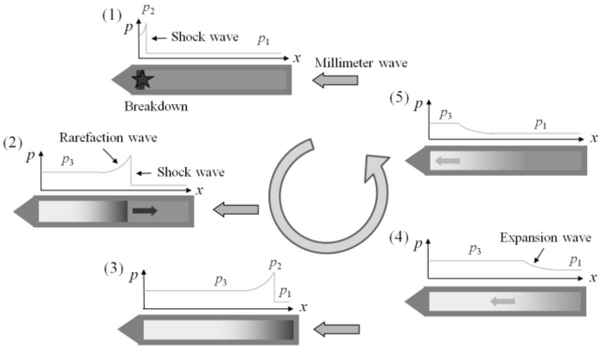

Fig.2. Thrust generation cycle of Microwave Rocket

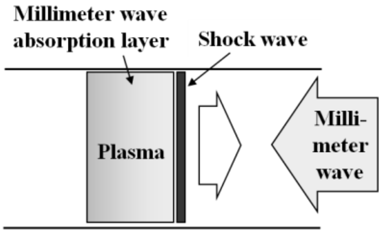

Fig.3. Propagating structure model of millimeter-wave supported detonation

2. Experimental Setup

170GHz gyrotron at JAEA was applied to a millimeter wave beam generator, the specifications of which is shown in Table I [5]. A Gaussian profile beam was converted into a flat-top profile by quasi-optical phase correcting mirrors and the profile was shown in Fig. 4. Experiments were done in the condition of 200kW power. The pressure on the parabolic reflector was measured by a high-speed pressure gauge (603B, Kistler Co., Ltd.), and the propagating velocity of the ionization front was detected by the home-movie camera images with changing of the beam pulse duration.

Table I. Specifications of the JAEA’s gyroton

Parameters	Values
Millimeter wave frequency	170GHz (1.73mm)
Output power at the peak	0.2-1MW
Pulse duration time	0.1ms to 1000s
Beam profile	Gaussian (HE11)
Beam diameter	40.8mm (at waist)
Electrical efficiency	50-60%

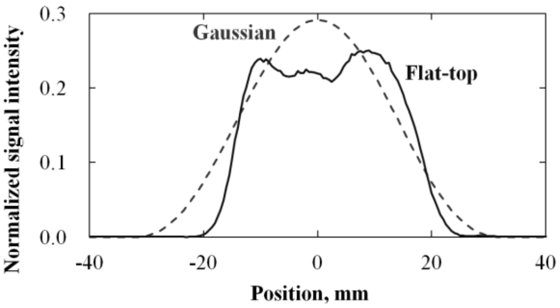

Fig.4. Beam profiles of Gaussian and flat-top

3. Results and Discussions

Figure 5 shows plasma structures with two different beam profiles, and the Plateau pressure at the thrust wall was shown in Fig. 6. Table II shows these results with analyzed thrust performance values. As a result, the propagating velocity of the ionization front of the flat-top beam was around a half of that of the Gaussian beam due to the lower peak power density, and this slower velocity affected the pressure induced inside the thruster. While the propagation was slow, the fluid inside the thruster could obtain high enthalpy from the beam, thus it generated the higher plateau pressure and higher thrust impulse. The thrust impulse was estimated by the integral of the pressure history at the thrust wall.

Table II. Results of Gaussian and flat-top beam

	Gaussian	Flat-top
Peak power density	33kW/cm^2	16kW/cm^2
Propagating velocity of ionization front	140m/s	68m/s
Plateau pressure	7.8kPa	14.4kPa
Thrust impulse	13.2mNs	28.4mNs
C_m = thrust / input power	93N/MW	199N/MW

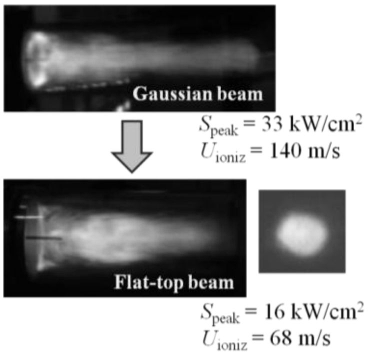

Fig.5. Plasma structures with different beam profiles

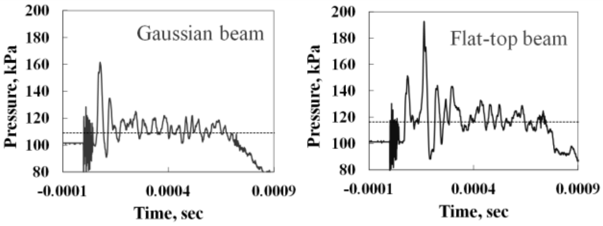

Fig.6. Plateau pressure increment by the flat-top profile

4. Conclusion

To reduce the detonation wave velocity and to enhance the thrust performance, a Gaussian profile beam was converted into a flat-top profile by quasi-optical phase correcting mirrors. As a result, thrust performance was enhanced by reducing the propagating velocity of ionization front.

Acknowledgments

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