Fast-Framing Observation of Filamentary Plasma in Atmospheric Millimeter-Wave Breakdown

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Abstract

Filamentary plasma is generated by high-power millimeter-wave beam in atmosphere. A 170 GHz sub-megawatt power gyrotron was used as the beam source. A beam profile was converted by a pair of phase-correction mirrors from Gaussian-like into flat-top, in order to investigate the way of the filamentary plasma generation. The propagation of the plasma was changed by the profile and it was observed by fast-framing cameras. The wall pressure was measured on the focusing reflector in the case with a cylindrical tube to keep the pressurized air heated by the beam energy. As a result, the plateau pressure obtained by a flat-top beam is higher than that of a Gaussian-like beam at the same propagating velocity condition of the ionization front.

Keywords: Plasma application, Plasma propulsion, Atmospheric breakdown, Millimeter-wave, Fast-framing imaging, Phase-correction mirror.

1. Introduction

The millimeter wave (MMW) is an electro-magnetic wave which has millimeter-order wave-length and its frequency ranges are lying from 30 GHz to 300 GHz. This range is between visible-light and radio-wave and its oscillation had been difficult until the invention of a gyrotron oscillator. Gyrotrons have been developed for electron heating and current driving in a thermal fusion reactor, and recently their use for other purposes were considered. One of the most interesting phenomena is millimeter-wave breakdown in the atmosphere, utilized in a detonation type of beamed-energy rocket[1)].

MMW breakdown is the phenomenon in which an incident high-power MMW accumulates ionization of gas around the beam. Observed plasma structure changes with beam mode, power density and ambient pressure[2,3)]. In an atmospheric breakdown by a high-power MMW, an exposed picture of the plasma shows a filamentary line formation at a certain high power density beam condition (**Fig.1**). In previous studies, the plasma was taken by a fast-framing camera, and the filamentary structure was formed by a propagation of many small particles of plasma[1-3)].

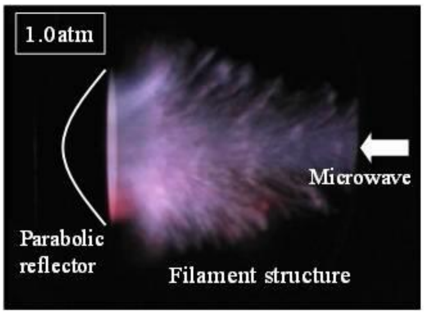

Fig.1 An exposed image of a filamentary plasma.

In this study, atmospheric MMW plasma was generated in some different conditions. A beam profile was converted by a pair of phase-correction mirrors from Gaussian-like into flat-top, in order to investigate the way of the filamentary plasma generation.

2. Experimental Setup

A 170 GHz gyrotron at JAEA[4)] was applied to a MMW beam generator, the specifications of which is shown in **Table 1**. A Gaussian-like profile of the incident beam was converted into a flat-top profile by using a pair of quasi-optical phase-correction mirrors. **Figure 2** shows the schematic of this system and the profile obtained by the system is shown in **Fig.3**. The power condition of experiments were changed from 200 kW to 600 kW.

Table 1 Experimental conditions of the incident beam.

Beam source	170 GHz gyrotron (wavelength: 1.76 mm)
Beam power	200 – 600 kW, variable (constant during a pulse)
Pulse duration	0.2 – 2.0 ms, variable
Beam pattern	Gaussian-like (HE_{11} mode)
Beam radius (at the spot size)	20.4 mm for 60 mm dia. reflector 10.2 mm for 40 mm dia. reflector

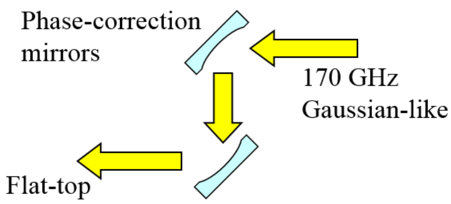

Fig.2 Schematic of a beam profile conversion system.

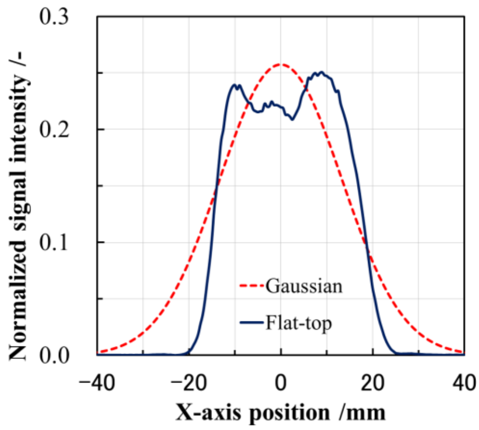

Fig.3 Beam profiles. (Gaussian: calculation, Flat-top: measurement by low-power test system)

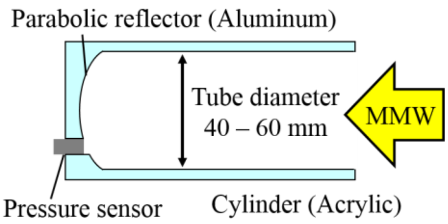

Fig.4 Schematic of breakdown and pressure measurement system.

Breakdown was generated by focusing the beam at a parabolic reflector. Plasma images were taken by a fast-framing cameras (GX-8, ULTRA Cam by nac Image Technology Inc.), and the propagating velocity of the ionization front was analyzed by the images. **Figure 4** shows the schematic of breakdown and pressure measurement system. The wall pressure on the parabolic reflector was measured by a high-speed pressure gauge (603B by Kistler Co., Ltd.). The pressure is obtained in the case with a cylindrical tube to keep the pressurized air heated by the beam energy, and it is called plateau pressure.

3. Results and Discussions

Figure 5 shows plasma formations with two different beam profiles. As a result, the granular plasma is ionized at the strongly-powered area, and its propagation formation and velocity seem to be dependent on the local power density distribution.

Figure 6 shows relationships between the propagating velocity of ionization front and the plateau pressure at the focusing reflector. As a result, the plateau pressure obtained by a flat-top beam is higher than that of a Gaussian-like beam at the same propagating velocity condition of the ionization front.

In the sense of the utilization as a detonation-type beamed-energy rocket, higher plateau pressure with slower propagating velocity at the same input power has higher thrust efficiency. As a result, flat-top beam leads higher plateau pressure than Gaussian-like one at the same input power condition.

Fig.5 Short exposure images taken by a fast-framing camera (exposure time: 1000 ns, left: Gaussian-like, right: flat-top, beam direction: from right to left)

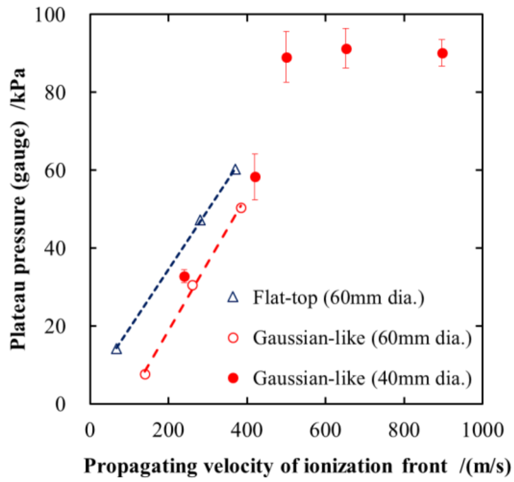

Fig.6 Relationships between propagating velocity and wall pressure at the focusing reflector.

4. Conclusions

Filamentary plasma is generated by high-power 170 GHz MMW with a Gaussian-like and flat-top profile. The propagation of the plasma was changed by the profile and it was observed by fast-framing cameras. The plateau pressure on the focusing reflector was measured in the case with a cylindrical tube. As a result, the pressure obtained by a flat-top beam is higher than that of a Gaussian-like beam.

References

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