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Experimental investigation on millimeter-wave discharge induced in gas

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The millimeter-wave discharge induced in gas is an important phenomenon in the use of the high power millimeter wave.

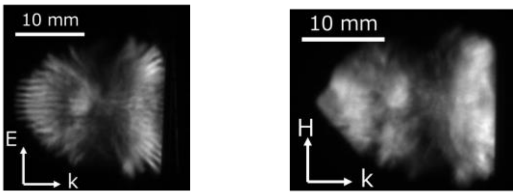
The gas discharge by electromagnetic waves is categorized into overcritical and subcritical conditions depending on the incident beam intensity. Under the overcritical condition, the beam intensity is slightly lower than the ionization threshold. The incident beam and the beam reflected from the plasma surface form a standing wave. The local intensity at the antinode of the standing wave exceeds the ionization threshold. The ionization front jumps by one-quarter of the wavelength. Thus, a discrete filamentary array ($\lambda/4$ structure) is formed. The ionization front propagates toward the beam source at the velocity of the order of 10^5 m/s to 10^4 m/s[1].

Under the subcritical condition, while the beam intensity is much lower than the ionization threshold even in the standing wave, the ionization front still propagates toward the beam source. According to a numerical model under the subcritical condition, the reduction of the gas density in the discharge region due to the Joule heating of the ambient gas contributes to the ionization induced by the collision between electrons and neutral partials of the gas [2,3]. In this case, the propagation velocity is in the order of the sonic velocity and a strong shock wave is driven [4,5].

The experimental data of the millimeter-wave discharge is limited especially for the subcritical condition, because of lack of available power source. Currently, a gyrotron is the only device that can deliver such high power in this frequency range.

We investigated the millimeter wave discharge in air using a high-power 303 GHz gyrotron developed by Research Center for Development of Far-Infrared Region. A high-speed camera with high spatial resolution was used to see the discharge structure.

Seed electrons are necessary to generate the discharge under the subcritical condition. A parabolic mirror was set in front of the beam source to focus the incident beam. The gas discharge is ignited at the focal point of the parabolic mirror. At the focal point, the discharge is under the overcritical condition and the ionization front propagates to the mirror side. The $\lambda/4$ structure was observed as expected. After the discharge ignition, the incident beam is cutoff by a high-density plasma. Because of the increase in the plasma diameter and the ionization front propagation, the beam intensity on the ionization front decreases and the overcritical condition terminates.



a) E plane b) H plane

Fig.1 Time-integral image of the millimeter-wave discharge. The incident beam propagates form left to right.

The plasma then turn into the subcritical condition. In this condition, the discharge structure transforms much slower than the overcritical condition and the ionization front propagates toward the beam source.

Figure 2 shows the millimeter wave discharge under the subcritical condition. In this measurement, it was found that the $\lambda/4$ structure generated under the overcritical condition begun to separate into granular plasmas under the subcritical condition. In the electric filed plane parallel to the wave vector and electric field vector of the incident beam, filaments formed parallel to the incident beam(Fig.1 a). The pitch size between each filament was estimated to 0.8λ. This pitch size nearly agrees with that in the excrements at 170 GHz [4] within error.

On the other hand, in the magnetic field plane, cloud like plasma was observed. The granular plasma was diffused and no filament was formed (Fig.1 b). Thus, the discharge structure under the subcritical condition may form a multi-layer structure. The filaments may be explained as sheets.

The difference of the discharge structure under the subcritical condition was observed for the first time.

References

[1] Y. Hidaka, E. M. Choi, et. al 2008 Phys. Rev. Lett., 100, 035003

[2] 6.2 O. I. Voskoboinikova, S. L. Ginzburg, et. al 2002 Tech. Phys., 47, 955

[3] 6.3 M. Takahashi,Y. Kageyama, et. al 2017 AIP Advances, 7, 055206

[4] 6.4 Y. Oda, K. Kajiwara, et. al 2009 Japanese J. of Appl. Phys. 48, 116001

[5] 6.5 T. Yamaguchi, Y. Nakamura, et. al 2015 J. of IAPS, 23, 42