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ヘリウム中を伝播する高速電離波のパルス繰返し周波数効果の機構

Mechanism of Pulse Repetition Rate Effects on Fast Ionization Wave in Helium

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Nanosecond pulse discharges have been used for high pressure plasma processes and plasma flow control applications. It is well known that the pulse repetition rate has a strong impact on the behavior of the nanosecond pulse discharges and their performance in the applications. Therefore, understanding the effect of pulse repetition rate on the nanosecond pulse discharge is very important, since this may lead to a key to control the role of the plasma for applications.

In this work, the Fast Ionization Wave (FIW) discharge in helium is selected to investigate this pulse repetition rate effect. This is because its operation is both stable and reproducible, free of jitters that are often found in other high pressure nanosecond discharges. This feature is crucial for a reliable measurement of the discharge parameters. In addition, findings on the FIW discharges can be useful for the understanding and control of other high pressure discharges, such as the atmospheric pressure plasma jet and the surface dielectric barrier discharge, due to their similarity in the discharge propagation features and the discharge cell geometry.

In the experiment, the repetitive FIW discharge characteristics are investigated with a capacitive potential probe for the breakdown electric field measurement and with the optical emission spectroscopy for electron energy estimation at the FIW front. Since the helium atomic metastable is one of the most important residues in the afterglow，its decay is measured by the diode laser absorption spectroscopy. With these temporally and spatially resolved diagnostics, the influence of the pulse repetition rate on the breakdown field, the emission intensity, and the metastable density is observed. The breakdown field tends to decrease with the increase of pulse repetition rate. This is caused by the increase of the residual electrons generated via Penning ionization, as predicted by a quasi-one-dimensional analytical FIW model implementing the residual electron effect. The breakdown electric field from the model agrees well with the measurement at high pulse repetition rate, while at the low pulse repetition rate, the model significantly underestimates the breakdown field. A possible reason is that the model does not take into account energetic non-local electrons, which are more pronounced at the low pulse repetition rate. These electrons are generated at the FIW front and travel backward. This argument is supported by the experimental evidences that (1) the measured electric field at the FIW front exceeds the runaway electron threshold and (2) the excited helium ion emission line is quite strong behind the FIW front. The importance of the high energy electron on the FIW propagation is also qualitatively discussed with the analytic model.

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