Studies of Nanosecond Pulsed Plasmas at Atmospheric-Pressure Using Laser Thomson Scattering

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論 文 内 容 の 要 旨

Non-thermal atmospheric-pressure plasmas have received much attention due to their substantial capacity for application in the fields of plasmas, such as plasma nanoscience, plasma medicine, and plasma chemistry. In applications of such plasma sources, radicals generated inside the plasma play key roles in the resultant of chemical reactions. Since the generation of radicals is governed by the presence of free electrons in plasmas, measurements of the electron density (n_e) and electron temperature (T_e) are essential for understanding plasma behavior. On the other hand, the most input power is supplied by electrons in non-thermal plasmas. Hence, to improve plasma devices efficiency, knowing the plasma parameters is so important.

The purpose of this research is applying laser Thomson scattering (LTS) method as a diagnostics system to measure n_e and T_e in non-thermal atmospheric pressure plasmas such as capacity coupled discharge (CCD), dielectric barrier discharge (DBD), and the early stage of the high-voltage waveform that is called primary streamer.

Capacity coupled discharge (CCD) has been selected as a non-thermal atmospheric pressure plasma. Since CCD does not have a dielectric layer between discharge electrodes, the formation time and the spatial position of the CCD plasma could be controlled. The spatial distribution and temporal variation of n_e and T_e have been examined. At the center of the discharge, n_e and T_e has been estimated to be 4.6 (± 0.6)×10^{22} m^{-3} and 1.7 (± 0.3) eV, respectively, at the time of 15 ns after the start of the discharge. A significant deference has been observed in temporal behavior between n_e and T_e after the discharge generation. Temporal behavior of n_e and T_e are discussed on the basis of two recombination processes: three-body electron-ion recombination because of high electron density and electron-ion dissociative recombination due to the formation of dimer ion in high pressure. Both of these mechanisms are operative in this system. The rapid decrease of T_e until 35 ns can be explained by two processes: the termination of power input to the discharge and the energy transfer by elastic collisions between the electrons and neutral particles or ions. Assuming the above values (n_e and T_e), the total collision frequency is estimated to be approximately 1×10^{12} Hz. The thermal relaxation time of electrons with neutral particles is calculated to be less than 20 ns. Considering this time, it is understood that the energy of the electrons can be transferred to the neutral particles in a short time. On the other hand, the decrease of T_e is gradual after 35 ns. It has been suggested that the three-body recombination process can be a heating source for electrons because the third electron of the process can obtain a part of the ionization-energy released by the process. The obtained results are useful for discussing the particle and power balances of the discharge plasma.

In addition, LTS measurements have been successfully applied to DBD. Temporal evolution of electron density and temperature were found to be similar to those of CCD. Because the total current charge for DBD was a fifth of that of CCD described above, the electron density of DBD was relatively low and was $(1.03 \pm 0.08)\times 10^{22}$ m^{-3} at a time of 15 ns at the center of the discharge.

Furthermore, the LTS method has been developed to diagnose streamer plasmas. The LTS signals were detected clearly and the values of n_e and T_e of the streamer were obtained for the first time. In order to avoid laser perturbation and obtain sufficient intensity of Thomson scattering signal, two cylindrical lenses have been employed to optimize spot size of a probing laser at a focusing point. The electron density and electron temperature were successfully measured to be $\sim 10^{18}$ m^{-3} and ~2 eV, respectively in the initial stage of the primary streamer. As time passes, the electron density and electron temperature decreased to their minimum values. These features of the streamer were found to be consistent with reported simulation-results.